Comparison of damage assessment methods of coconut rhinoceros beetle (*Oryctes rhinoceros*)

A thesis
submitted in partial fulfilment
of the requirements for the Degree of
Master of Science

at
Lincoln University
by
Balanama (Bala) Asigau

Lincoln University
2021

Abstract of a thesis submitted in partial fulfilment of the requirements for the Degree of Master of Science.

Comparison of damage assessment methods for coconut rhinoceros beetle (*Oryctes rhinoceros*).

by

Balanama (Bala) Asigau

Oryctes rhinoceros (L.) (Coleoptera: Scarabaeidae), most commonly known as the coconut rhinoceros beetle or CRB, is an invasive pest that affects palms, especially coconut (*Cocos nucifera*) and oil palm (*Elaeis guineensis*) and their effects can be detrimental. For the past 40 years, CRB population has been controlled by the biological control *Oryctes* nudivirus (OrNV), however, a recent incursion causing adverse impacts in the Pacific has prompted researchers to re-evaluate the existing management approaches, so effective population control can be achieved once again. A vital component of these management process that is often overlooked, is the need for a robust damage assessment and monitoring tool. Various damage assessment methods have been developed and the use of damage scales has been the most common among them, however, their accuracy and potential to monitor changes over time have not been explored. This study aimed to achieve two main objectives: 1) To compare and identify the capability of 3 damage scales, binary, 3-point and 5-point, in assessing damage severity levels and monitoring changes that occur over time and 2) To determine whether assessors affected the accuracy of the 3 damage scales.

Photographs from a historical collection of CRB studies done over the years in the Solomon Islands, Papua New Guinea and Fiji were used to test the capabilities of the scales. These countries were selected due to their differing CRB status. The influence of assessors was tested with data that was collated from an online survey with respondents including those with no knowledge of CRB and experts in the field.

The results indicated that damage intensity levels can be measured through the 5-point scale, but the accuracy within the scale is low compared to the binary and 3-point scales. The study also found that detecting changes over time is feasible however, it was difficult to determine the minimum detectable effect size. A brief simulation study found that the effect size in a sample of 100 undamaged palms is at 6% in the binary and 3-point scale. It was recommended that for effective monitoring of changes a

sample population of 100 or more palms is required. Given that change was detectable after a minimum of 2 years, it is practical that monitoring periods are scheduled biannually. The online survey revealed that experience increases the accuracy of the damage scales among assessors, nevertheless, training still remains a vital requirement in the use of the scales if accurate and reliable results are expected.

Keywords: *Oryctes rhinoceros*, coconut rhinoceros beetle, damage assessment, damage scale, binary, 3-point, 5-point, Solomon Islands, Papua New Guinea, Fiji, assessor influence, accuracy, damage intensity, change over time.

Acknowledgements

My two-year journey in New Zealand has been an amazing, life-changing experience. First of all, I praise the Almighty God who provided me with this opportunity and guided me through this journey. I also express heartfelt appreciation to the Government and people of New Zealand for granting me this opportunity to read for my Masters at Lincoln University 'Te Whare Wanaka o Aoraki'.

I would like to express my sincere gratitude to my principal supervisor Dr Sarah Mansfield for her continuous support, guidance, encouragement, enthusiasm and immense knowledge of my Master's study and research here at Lincoln University. I also convey deep appreciation to my associate supervisor Senior lecturer Mike Bowie for his advice and corrections during my thesis journey. I would like to thank Dr Trevor Jackson for his guidance throughout my research, it was a pleasure to work with experienced people like you and I am grateful for the knowledge you have imparted in me. I would also like to extend my gratitude to Chikako van Koten for teaching and helping me with everything data analysis. I also wish to acknowledge the staff of the Department of Bio-protection and Research Centre and a wider appreciation to the Faculty of Agriculture and Life Sciences. I would also like to extend my gratitude to AgResearch and the CRB project team who have also contributed to my growth as a researcher. My appreciation also goes to the New Zealand Aid Scholarship administration team at Lincoln University for their support.

I wish to express thanks to all respondents who participated in my research for without their participation, this thesis would not have been possible. I am also very grateful to all my friends and colleagues at Lincoln University who supported and encouraged me during my study because without them this journey would not have been such a success.

Last but not the least, my deepest appreciation belongs to my family, my parents Willie and Elizabeth Asigau, my siblings, Nou, Leana (to whom I dedicate this thesis), Elizabeth, my sister in-law Cecilia, my nephews Nanadai jnr and Alexander Leana and to my best friend Randel for your support, encouragement and prayers throughout this research journey.

Many thanks to you all and god's blessings.

''Ngā mihinui ki a koutou me ngā manaaki atua.''

Table of Contents

List of Tables

List of Figures

Chapter 1

Introduction

This chapter presents the importance of coconuts in Pacific Island countries and a brief description of coconut rhinoceros beetle, *Oryctes rhinoceros* and how it affects palm growth. This is followed by the purpose and significance of the thesis and concludes with an outline of the thesis.

1.1 The coconut rhinoceros beetle

Oryctes rhinoceros (L.) (Coleoptera: Scarabaeidae), most commonly known as the coconut rhinoceros beetle or CRB for short, is a pest of palms, especially to coconut (*Cocos nucifera*) and oil palm (*Elaeis guineensis*). The beetle is invasive and though its exact origin is unknown, it is endemic to the tropical regions in Asia, including West Pakistan, India, China Thailand, Malaysia and the Philippines (Bedford, 1980; Catley, 1969; Gressitt, 1953; Young, 1975). CRB was accidentally introduced into the Pacific through the island of Upolu in Western Samoa in the year 1909, probably through rubber seedling pot plants from Ceylon (Bedford, 1980; Catley, 1969; Marshall, Moore, Vaqalo, Noble, & Jackson, 2017) and eventually found its way to other Pacific Island countries causing damage to palms in Tonga (1921), Wallis and Futuna (1931), Papua New Guinea (1942), Palau (1942), Tokelau (1963) and Fiji (1953). Fortunately, in 1963 a viral pathogen, *Oryctes rhinoceros* nudivirus (OrNV) was discovered in Malaysia and proved to control the original CRB population successfully. Years after this discovery, OrNV was introduced to the Pacific, successfully establishing itself and effectively managing and suppressing the CRB population to an appropriately manageable level. Since then, OrNV has been proven to effectively control CRB and minimize its impacts on coconut palms.

For almost 40 years, OrNV had managed to control the CRB population that was harmful to the palm industries where it occurred. However, in 2007, an unexpected CRB incursion was reported from Guam (Marshall et al., 2017), and was described as highly invasive with the ability to rapidly establish itself to its environment and cause significant damage (Pacific Community (SPC), 2017). These observations raised concerns and soon research into the identification and effective control measures were initiated. The CRB population found in Guam was identified as a different biotype and termed CRB-G (G for Guam) (Marshall, Moore, & Vaqalo, 2016). Soon after its identification, an attempt to introduce OrNV for the control of CRB-G was made but the results were unsuccessful and the possibility of CRB-G being a tolerant or resistant biotype to the original strain of OrNV was proposed (Ero, 2015; Jackson & Marshall, 2017; Marshall et al., 2016; Vaqalo, Timote, Baiculacula, Suda, & Kwainarara, 2017) and work into finding an effective control was initiated. Since the incursion in Guam, the distribution of CRB-G has expanded to PNG (2009), Hawaii (2014), Palau (2014), Solomon Islands (2015) and New

Caledonia (2019) (Ero, 2015; Etebari, Filipovic, et al., 2020; Pacific Community (SPC), 2017; Vaqalo et al., 2017).

1.2 The life cycle of *Oryctes rhinoceros*, coconut rhinoceros beetle (CRB)

The life cycle of CRB usually lasts for about 11-14 months (Figure 1-1) (Bedford, 1980; Gressitt, 1953; Moore, 2018) but can also be as little as 5 months depending on adequate food, temperature and humidity (Jackson, Marshall, Mansfield & Atumurirava, 2020). CRB undergoes the typical life cycle stages of a scarab from egg through to adult with a larva (includes three instars) and pupal stage and majority of this lifecycle is spent in the non-damaging egg, larval and pupa stages (USDA, 2015). Of the non-damaging life stages, only the larvae feed and generally, only feed on decomposed organic matter therefore do not cause direct damage to coconut palms (Gressit, 1953; Catley, 1969, Hinckley, 1973; Bedford, 1980).

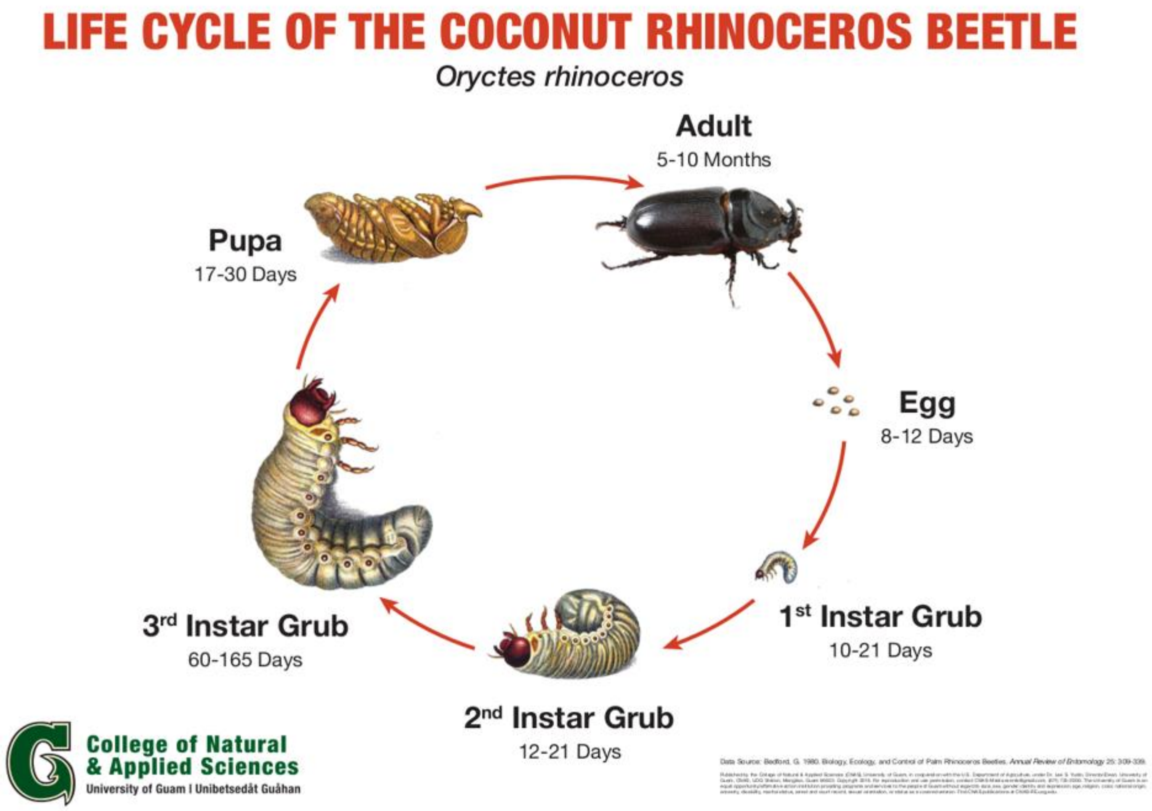


Figure 1-1: Life cycle of *Oryctes rhinoceros* (Moore, 2018)

The adult stage of the beetle is very damaging and can last between 5–10 months (Moore, 2018) with the females having the potential to lay an estimation of 100 eggs per female (Jackson et al., 2020). CRB is a serious pest because of the feeding characteristics the adult beetle possesses (Gressitt, 1953; Moore, 2018). This feeding characteristic have the potential to reduce photosynthetic area thus reducing nut yields (Bailey, O'Sullivant, & Perry, 1977; Bedford, 1980; Hinckley, 1973). The damage occurs when the adult beetles start to feed. To feed, the adult beetles emerge from breeding sites at night and fly to the higher axils of the coconut palms or alternative host palms in the absence of coconut palms (Gressitt, 1953). The adult beetles burrow their way into the centre of the palm using their clypeus horn and fore tibiae to bore and mandibles to chisel and chew on the juices of the macerated cell tracts (Gressitt, 1953). These feeding characteristics produce frass at entry points and boreholes. They also produce v-cuts or wedged-shaped gaps on fronds which are a distinctive symptom specific to CRB damage (Bedford, 1980; Gressitt, 1953; Hinckley, 1973). Severe frond damage and repeated attacks on mature palms by the adult CRB can lead to defoliation and potentially kill the palm.

1.3 Coconut palm growth

CRB affects the growth of palms, and the impacts of the beetle's damage can lead to yield loss and the eventual death of coconut palms (CABI, 2020). The interpretation of the effects of attacks on palms is reliant on the understanding of the growth and morphology of the palms (Young, 1975) so essentially these will be covered in this section of the thesis. Additionally, due to literature that suggests that the beetle is found to primarily attack palms that are already several years of age and only rarely on very young seedlings up to 3-year-old palms (Bedford, 1976; Gressitt, 1953), the descriptions of palm and frond growth in this section are of the view that palms are matured and have existing mature fronds.

A mature coconut palm is surrounded by a crown of about 20–35 fronds during its lifespan depending on how suitable the environment is (Foale, 2003) and on average, produces around 12–16 fronds annually (Jackson et al., 2021; Santos, Batugal, Othman, Baudouin, & Labouisse, 1996). A frond goes through growth stages from formation in the growing point through to its fully functional state then senescence which takes around 2–3 years. The understanding of these growth stages is vital in that they aid in monitoring and estimating the presence and activity of CRB. A new frond develops in the growing point and emerges as a developing spear at approximately three months (Jackson et al., 2021), then it takes about another three to six months for this developing spear to reach its full length (Young, 1975). In the spear-like structure, are tightly folded leaflets compacted against the rachis that are protected by a leaf stipule fibrous cover. As growth occurs, the spear pushes through this fibrous cover, gradually exposing the leaf stalk and this growth process persists until the leaflets open to become a fully functional frond. The opening of the leaflets takes 40–45 days to fully open from the tip of the frond to the bottom and once they are fully open, they slowly flex away from the stem (Young, 1975).

Many authors have described the difficulty of detecting *Oryctes rhinoceros* often relating it to the cryptic nature and nocturnal behaviour of the beetle but have agreed that one of the most common and first indicators of establishing CRB presence is through identifying the distinctive notches produced by the feeding adults (Young, 1986). The purpose of the importance of palm growth in this context is that palm growth appears as a biological clock that enables you to estimate the beetle's first incursion in an area and allows you to monitor changes over time (Jackson et al., 2021). This information can also provide an avenue that allows you to monitor whether management efforts are effective or not.

The estimated overall frond growth process from growing point (central axis) to shedding in a coconut palm takes about 2–3 years (Santos et al., 1996; Young, 1975) with Young (1975) adding that growth is faster in mature palms (average of 16 fronds/year) as compared to younger palms that produce around 8–14 fronds per year. According to Foale (2003), every frond on the crown conforms to a set of a geometrical pattern of angular separation around the circumference of the palm truck from the time it emerges. They also are said to have an alternate or 2/5 phyllotaxis where five fronds are produced before the completion of 2 complete revolutions (Davis, 1971; Young, 1975). According to the growth timeline for an individual frond, each frond emerges 6 weeks after the previous one which means that the growth space between the fronds is 1.5 months apart.

From this information about palm growth, we can gather that in 2 revolutions there are 5 fronds and if each frond is 1.5 months apart then these 5 fronds represent a timeline of 6 months. In the context of identifying when an incursion has occurred, identifying the frond number can ideally provide you with information on when an incursion may have occurred. According to Jackson, Mansfield, and Atumurirava (2020), any incursion that occurred in the last 6 months can be picked up from the topmost 4 to 5 fronds on the palm crown. With the same estimation, any damage symptom sighted between the 5th and 9th frond could indicate an incursion in the previous 12 months. In the same context of measuring the timeline of damage that has occurred using the growth rate of fronds, the impacts of control measures or palm recovery can be monitored.

1.4 Significance of Coconuts (*Cocos nucifera*) & *Oryctes rhinoceros* in the Pacific

The coconut palm is found throughout all tropical and subtropical regions where it plays a significant role in the livelihoods of the local communities. The crop is versatile and provides for household and wider societal needs for almost all the necessities in life: food, fibre, drink, oil, medicine, mats, fuel and local utensils (Chan & Elevitch, 2006). Coconuts are particularly essential in Pacific societies where they serve as an important small-holder crop contributing to food security, nutrition, employment and income generation (Batugal, 1999; Gitau, Gurr, Dewhurts, Fletcher, & Mitchell, 2009). Globally, Pacific Island countries account for 3–6% of coconut oil exports annually and make up 5% of the world's copra production (McGregor & Sheehy, 2017). Over 50% of the world copra exports is made up of the Pacific Island countries with Papua New Guinea being the largest copra exporter (McGregor & Sheehy, 2017). The coconut industry in Papua New Guinea provides employment or sustenance for about 2.6 million of the country's population and on average contributes K126.5 million annually to the country's economy through its export revenue (Kokonas Indastri Koporesen, 2017). While in the Solomon

Islands, the coconut industry is worth around SBD 140 million and supports over 40,000 rural households (Etebari et al., 2020).

However, the damage incurred by CRB has been proven to have adverse impacts on the crop and affect the livelihood of those that depend on it. An extensive study by Gressitt (1953) found CRB related losses estimated at 50% palm mortality on Palau's coconut palms in the first 10 years after its introduction to losses of US$1,100,00 to South Pacific countries from reduced yields in 1968 alone (Catley, 1969). Studies by Bailey et al. (1977) and Bedford (1980) through artificial defoliation have shown that a reduction in frond area has an impact on nut yields. These findings prove that yield production levels are affected but studies to determine an economic threshold have been inconclusive, due to the difficulty in establishing a pest density-damage-yield relationship under natural field conditions (Bailey et al., 1977).

1.5 Purpose & Justification of the thesis

Coconut is an essential crop in Pacific societies and contributes immensely to the sustenance of livelihoods in the region. However, its existence is threatened by an invasive beetle, *Oryctes rhinoceros*, commonly known as coconut rhinoceros beetle or CRB. CRB is a significant pest of palms and has the potential to cause devastating effects that pose a threat to the industry. The feeding and burrowing characteristics of the beetle can cause severe damage, which could result in lower coconut productivity and the eventual death of the palm. While there has been progress in the work to identifying effective control measures to minimize the impacts of CRB, little attention has been given to ensuring that some of the methods utilized in assessing the damage caused by CRB are indeed robust and support the efforts of mitigating the adverse effects on palms.

The results from this research, aim to identify suitable damage assessment tools to develop insect pest response and awareness materials towards effective monitoring and control of CRB. This aim is achievable if the damage assessment method identified is reliable and consistent. The findings of the study are expected to benefit farmers, extension workers and the coconut industries or research organization to assist in their efforts to effectively manage the invasive CRB.

1.6 Outline of the thesis

The thesis is divided into 5 parts. Chapter 2 reviews relevant literature on the use of damage assessments in CRB studies and presents an analytical outlook for inquiry. It concludes with the study hypothesis, research objectives and research questions. Chapter 3 describes the research design and approach. It explains the sampling, data collection and analysis techniques used in the study. Chapter 4 contains the results of the proposed research questions and Chapter 5 will discuss the results of the thesis and draw conclusion from them, furthermore presents avenues for further research.

Chapter 2

Literature Review

2.1 Introduction

This chapter reviews relevant literature on the use of damage assessments in CRB studies and presents an analytical outlook to summarise the need to standardize methods that will assist in the efforts to manage the impacts of the invasive beetle *Oryctes rhinoceros*.

2.2 Damage Assessments

The increasing geographical range of the recent incursion has prompted researchers to re-evaluate the existing management approaches so the CRB population can once again be controlled effectively (Marshall et al., 2016). A prevailing issue is that majority of the work has always been centred on the need for a biological control agent and less attention has been given to damage assessment and monitoring tools (Mansfield, pers. comm). Although the discovery of an effective bio-control agent is vital, what has lacked in the past research era and now, is testing the robustness of the monitoring tools including damage assessment methods.

Studies (Bailey et al., 1977; Bedford, 1976, 1980; Cumber, 1957; Ero, 2015; Gressitt, 1953; Jackson & Sailo, 2017; Vaqalo et al., 2017; Young, 1975; Zelazny & Alfiler, 1987) show that damage assessments play an important role in detecting the presence of CRB and identifying the severity of the beetle's damage to palms from when the beetle was first detected till today. Throughout the years, new methods have evolved, and others have been modified to suit the needs of different study objectives. Although this process has improved methods and introduced new ways of monitoring the damage from CRB, it has also created inconsistencies in damage assessment methods throughout the research era. The variations in methods make monitoring the changes and effects of both CRB and its biological control agent OrNV difficult. Without a standardized protocol, making comparisons of CRB damage between studies and countries is a challenging task.

Generally, research work subsided with the discovery of OrNV in the 1960s, resulting in a literature gap between the early research periods (1950 to 1980) following the invasion of CRB-S and the more recent work since 2009 relating to the CRB-G invasion in Guam. It can be assumed that these methods have the potential to assess the changes in damage over time, but the subject has not been properly explored (Bedford, 2013a, 2014). Numerous studies have been carried out in the past research era, however, none of the previous studies in the Pacific region has been replicated except Fiji (Bedford, 2013b). For example, no studies have been published from Samoa since 1982, 1981 for Tonga and 1977 for Tokelau Islands. While there have been many studies carried out in Papua New Guinea, none of them is a continuation of the earlier studies taken when CRB had first invaded PNG. The only record of a follow-up survey in any Pacific Island country is one from decades earlier by Bedford in 1976 which was re-trialled in Viti Levu, Fiji in 2010 (Bedford, 2013b). This remains the only record for any Pacific Island country replicating a survey since the establishment of OrNV.

Existing ways of detecting and assessing the effects of CRB infestation in previous studies included the use of artificial defoliation (Bailey et al., 1977; Bedford, 1980), pheromone and log trapping (population counts) (Cumber, 1957; Zelazny & Alfiler, 1987), light trapping (wood, 1968), acoustic detection (Mankin & Moore, 2010), photographs (Ero, 2015; Jackson & Sailo, 2017; Vaqalo et al., 2017), visual inspection and the use of damage categories from binary, 4-point and 5-point scales. Some of these alternatives have had issues with poor accuracy and limited feasibility for use in large scale plantations (Bedford, 1980; Young, 1986). However, the conventional method of detection using frond defoliation remained frequent and the use of damage scales was a popular method throughout the research era. For the most recent studies (Ero, 2015; Jackson & Sailo, 2017; Vaqalo et al., 2017), with evolving technology, damage scales have been used together with photographs and geo-tags for recording locations of CRB affected areas.

2.3 Damage Scales

Damage assessment methods have evolved throughout the years including the structure of damage assessment scales. Knowledge of the quantity of damage is paramount particularly for decision-makers where the damage incurred has an impact on livelihoods. In the era of CRB research, damage scales have been used to attain information of damage caused by CRB on palms. Two forms of scales have been utilized, binary and multi-point scales. Binary scales were most commonly used in the past but have now transitioned to more sophisticated multi-point scales with 4–5-point grading categories. These scales are comprised of categorical descriptions of both quantitative and qualitative variables used to describe CRB damage.

Table 2-1: Damage assessments used in various CRB studies.

Author (year)	Country	Objective	Sampling method	Sample size	Assessment type	Grading
Gressit (1953)	Palau	Population counts	Whole palm assessment including nuts	Not defined	Binary	1. Living 2. Dead
Cumber (1957)	Western Samoa	Damage distribution in plantation	Frond assessment	plantation	3-point	Not specified
Young (1975)	Western Samoa	Understand how CRB damage occurs on palms and palm recovery after attacks from the beetle.	Fronds and petiole assessment	Not defined	Binary	1. Damage 2. No damage
Bedford (1980)		To judge the effectiveness of control measures	Random Frond assessment	20–30 palms	Binary	1. Damage 2. No damage
		To judge the effectiveness of control measures	Top 3–5 fronds of crown	25 visible palms (4 cornered observation)	Binary	1. Damage 2. No damage
Zelazny & Aliflier (1987)	Philippines	Population counts & estimating the number of beetle attacks/ha for a given month	Random Frond assessment	40 palms		Not specified
Bedford (2013)	Fiji	To judge the effectiveness of OrNV	Rapid damage survey Top 3–4 fronds	Not specified	Binary	1. Damage 2. No damage
		To judge the effectiveness of OrNV	Detailed damage survey Whole crown assessment	Not specified	Binary	1. Damage 2. No damage
Ero (2015)	PNG	Measure the Spread	Photographs of palm crown	$1km^2$ grid assessments Driving along main access roads or highways	Binary	1. Localised (<40% of damaged palms in $1km^2$) 2.Widespread (>40% of damaged palms in $1km^2$)
		Measure the severity	Photographs of palm crown	$1km^2$ grid assessments Driving along main access roads or highways	4-point	1. No defoliation 2. Light defoliation: 1–10% 3. Moderate: 11–30% 4. Severe >30%

Vaqalo et al (2017)	Solomon Islands	Used to determine the severity and spread	Frond palm crown assessment	Driving around taking photographs of palm crown 585 palms assessed	5-Point	1. No damage 2. Slight: 1–10% of fronds removed 3. Moderate: 11–50% of fronds removed 4. Severe damage: 50–95% 5. Dead/ unrecoverable: 95–100%
Jackson & Sailo (2017)	Fiji	Used to determine the level of damage	Frond assessment	Pictures	4-Point	1. 0: No defoliation 2. Low: <10% defoliation 3. Medium: 10–30% defoliation 4. High: >30 defoliation

2.3.1 Damage scales used in CRB studies

Binary Scales

Binary scales are nominal and consist of items that assume one of two possible values, such as yes or no and true or false. The binary scales in CRB studies used qualitative descriptions such as damage versus no damage and living versus dead to identify the presence of CRB in an area. In CRB studies, binary scales came into play as early as the 1950s when Gressitt (1953) used damage symptoms of CRB to identify their presence and the number of beetles present. The scale was further explored by Young (1975) and Bedford (1980) in their aim to understand beetle damage, palm recovery and as a method to judge the effectiveness of control measures that were being implemented respectively. From the way surveys were carried out in the past, binary scales were observed collectively as an ideal method to survey larger areas because damage could be assessed relatively quickly using this method. In a more recent survey, Ero (2015) used this approach to measure the spread of CRB across a length of $1km^2$ land area giving him estimates of how localised or widespread CRB is in seven lowland provinces in Papua New Guinea.

Along with the scale's ability to assess damage in larger areas, the study by Bedford showed that binary scale is versatile, in that, modifications could be made to the assessment protocol to accommodate the type of survey that is required. Both rapid and detailed surveys in his study were done through this method, except, rapid surveys involved reducing the assessment to only the youngest fronds (first 3–5 youngest fronds), while more detailed surveys assessed the whole palm to measure the proportion of damaged fronds per palm. So ideally, binary scale data could capture the beetle presence, the presence of damage and to an extent measure the spread of impact of CRB. Young (1975) described binary scales as an objective and simple to use method for the assessment of damage by CRB.

Although binary scales are effective for their purpose in measuring damage, the scale has some limitations. The binary scale's capability in detecting damage is evident, however, it cannot measure the severity of the damage. Ideally, most of the past literature provides the information for the absence or presence of damage but the damage is difficult to quantify, and this potentially can have an impact on monitoring. This was evident from the studies conducted in Western Samoa when OrNV establishment and its effectiveness in reducing the population could not be associated with the growth of palms because the damage surveys carried out lacked quantitative data (Bedford, 1980). In this scale, the variations of the damage within the "damage" category potentially show a level of ambiguity given that the category for damage represents a damage range from 1–95% damage. Whilst it is an indication of damage, it is not the ideal measurement for assessing the intensity of the damage incurred and in turn makes it difficult to monitor changes over time.

An issue over the scale's reliability was raised by Bedford (1980) who stated the reliability of the binary scale is dependent on the number of assessors and assumed that an increased number of assessors would give more reliable answers compared to a single assessor. This assumption however has not been trialled in any progressive studies and remains empirical. According to Meadows and Billington, (2005), reliability can only be ensured when objective answers are unambiguously right or wrong. Reliability is the extent to which the results can be reproduced when the research is repeated under the same conditions (Middleton, 2020). Given Bedford's recommendation where an increase in observers has the potential to increase the scale's reliability, consistency between different observers is paramount. However, in general, visual perceptions vary amongst individuals and influences how they score damage (Smith, Pinkard, Stone, Battaglia, & Mohammed, 2005). A review by Bock, Poole, Parker, and Gottwald (2010), on pathological disease assessments, encompasses many of the variations and errors that exist with visual and digital photography assessments that can potentially apply to the context of assessing CRB damage. Some of which include, the different assessing abilities of each assessor, disease estimation and plant size and structure.

Multi-point Scales

Multi-point scales are popular in social science studies where quantitative measures are utilized to measure a variable of interest reliably and validly (Kilne, 2000; Nevill, Lane, Kilgour, Bowes & Whyte, 2001). The use of multi-point damage scales was rare historically but has become more common in recent CRB studies (Ero, 2015; Jackson & Sailo, 2017; Vaqalo et al., 2017) and have been used consistently for the measure of damage severity of CRB on coconut palms. The multi-point scale (5-point) used by Vaqalo et al. (2017) was described as an effective method to determine the pest status in an area and a tool that aids in informed decision-making regarding pest responses and management. This alludes to the importance of having effective damage assessment tools which are paramount because inaccurate assessments can potentially impact epidemiological studies when the success or failure of the effectiveness of the management efforts is based on estimates of damage severity. Moreover, with the recommendations of Bedford (1980) that say an increase in the number of assessors can potentially increase the reliability of binary scales, the opinions of Vaqalo et al. (2017) differ for the multi-point damage assessment scale, stating they found that reliable data could still be attained even with fewer assessors. Again, these arguments remain empirical because the reliability, and validity of the scales have not been explored yet.

In the context of damage intensity, researchers that used the multi-point scales (Ero, 2015; Jackson & Sailo, 2017; Vaqalo et al., 2017) prove that the method can provide more specific data than the binary scales (Bedford, 1980; Gressitt, 1953; Young, 1975). This specific data is a result of the multi-point scale's ability to capture more data as compared to the binary scale which is confined to only two data values with broad and generic data information range. Ideally, a preferred outcome in measuring damage is when data collected is accurate and this can be ensured if the tools used for the task can obtain these results. Also, multi-point scales are subjective and are perceived that way because the increased number of categories would require more subjective assessment or judgement.

Although multi-point scales have featured the attributes to reliable damage assessments, these factors have not been entirely explored. Studies have found that with subjective content, assessments can become more technical or require trained personnel for usage. An attribute of subjective content in any assessment scale is that it indirectly requires assessors to utilize experience, which in turn can be subject to observer bias but currently in CRB studies there is no knowledge of the impact of observers in the way they use these multi-point scales, including the binary scale.

2.3.2 Assessor Influence

In research, observer bias is a form of detection bias originating at a study's stage of observing or recording information. Observer bias occurs when the investigator is aware of the disease status, treatment group or outcome of the subject and their ability to interview the subject, collect or analyse the data in an unbiased manner is compromised (Brown, 2010). The presence of observer bias is difficult to draw from the damage scales used in CRB damage assessment studies without testing the parameters that could potentially attribute to it, some of which may include profession, experience or familiarity of the subject just to name a few. There is not enough information from collected work to describe the status of observer bias with damage assessment scales for CRB studies. Historic studies of CRB damage were rarely duplicated so factors, such as observer bias, that could affect the damage scales are poorly understood.

As mentioned earlier, there are errors associated with visual and digital photography assessments, and most of these errors mainly stem out from an individual's intrinsic ability to make an assessment. Therefore, assessment tools developed must have attributes that reduce the level of error and so allow for an accurate and reliable data collection process.

The use of visual aids has been proven essential in damage assessment protocols due to their ability in reducing bias (Smith et al., 2005) and this is a feature mainly used in the multi-point scales. Their use in these scales is good because they aid the assessors to identify or estimate the level of damage to a palm. However, diagrammatic illustrations can also be somewhat subjective and inconsistent between users. In a damage grading scale for CRB, assessors are required to grade the level of damage which is indicated by the amount of frond defoliation on the palm crown. An issue with this form of assessment is the accurate interpretation of the original leaf/frond density when it is no longer present on the palm. A study carried out on eucalyptus trees by Smith et al. (2005), found the interpretation of whole leaf defoliation as a problematic component when measured against a crown damage index and associated that to the varying individual opinions of a healthy phenotypic expression for a particular site. Also, Bedford (1980) found that the local growing conditions of the palm including the type of soil, age and climatic conditions can affect the way a healthy palm is perceived and in turn influence the way a palm is graded. For the reasons of inaccurate estimations studies have found the use of diagrammatic illustrations to reduce subjectivity. A study by Godoy, Koga, and Canteri (2006) in using diagrammatic scales to assess the severity of soybean rust found that overestimation between raters was common and the use of standard area diagrams (SAD) improved raters' accuracy and precision levels. The use of absolute standard diagrams also was found by Redfern and Boswell (2004) as a good way to detect changes in crown conditions with time as opposed to using a local standard (a healthy tree under local growing conditions). In addition, using absolute standards to assess changes over time has its advantage in detecting geographical differences (Redfern & Boswell, 2004). This method reduces subjectivity and ensures consistency is maintained, thus encourages repeatability of methods.

Out of the two types of damage assessment scales, the multi-point scales are subjective and a concern with subjective content is that observers are prompted to use pre-existing experience or skills and overlook manuals or protocols when assessing the damage. For the use of scales in CRB damage assessment studies, the level of experience of the assessors in the use of the scales have never been studied thus not much is known yet about the effectiveness of these scales in relation to an individual's experience with CRB. Studies have found both experience and skills for visual assessments are prone to bias (Deutscher et al., 2003) and that observer experience was a major source of variation with subjective estimates that directly relate to the experience and training of the assessor (Innes, 1988). In contrast, Smith et al. (2005) found that experience and training were not the only attributes for consistent damage estimates between experienced and inexperienced assessors, instead, how well assessors comprehended the instructions and the efficient use of visual standards for the damage categories played a role in achieving similar results between assessors. This same study found that moderately experienced observers had the least accurate results, possibly due to overconfidence and elimination of their use of visual aids. According to Smith et al. (2005), the use of highly trained and experienced assessors along with pre-assessment calibration among assessors had the potential to attain reliable and accurate results. Seemingly, literature shows the damage categories in multi-point scales can determine the severity levels of CRB damage, however, their potential to assess changes over time have not been explored.

2.4 Hypothesis and research objectives and research questions

The study hypothesises that damage intensity and the changes over time can be detected using the binary and multi-point scales. However, the multi-point scales require a level of experience for them to be accurately used. In the existing pieces of literature, there are no studies that have explored the influence of observers against the scales. Most recent literature only show that damage intensity can be attained by the multi-point scales and that binary scales cannot gather quantitative data. However, the ability of the scales in detecting changes over time has never been explored. This study analyses the existing binary and multi-point scales used in CRB damage assessment studies and their ability in detecting damage intensity and the effect the type of observers has on the accuracy of the scales.

2.5 Research Objectives

The main objectives of this study are to:

1. To establish the capability of binary and multi-point scales in detecting damage intensity and changes that occur over time.

2. Determine whether observers affect the accuracy of the binary and multi-point scales.

3. Recommend any solutions that may improve the accuracy, reliability and validity of the binary and multi-point scales used in CRB damage assessment studies.

The two research questions corresponding to these objectives are:

1. Which scale can detect damage intensity and changes that occur over time?

2. Do the observers affect the accuracy of the data collected using the binary and multi-point scales?

Chapter 3
Methodology

3.1 Introduction

This chapter describes the research methods applied in this study to collect data and to test the propositions about the damage assessment scales used to identify CRB damage severity levels and monitoring the changes that occur over time.

3.2 Selection of study sites

The study sites for the research were selected from participating countries in the Pacific Islands under the New Zealand Ministry of Foreign Affairs and Trade Project “Pacific Response to Coconut Rhinoceros Beetle: Biocontrol and Integrated Pest management”. Three countries, Solomon Islands, Fiji and Papua New Guinea were identified and selected as suitable study sites because of their differing status and biotype of CRB. Both Papua New Guinea and Fiji have had a long-standing history of CRB and OrNV since the 1900s and 1980s respectively while the invasion of CRB in the Solomon Islands has only recently occurred affecting its coconut and oil palm industry. About the type of CRB population present in these study sites, the Solomon Islands and Papua New Guinea have the two CRB populations whereas Fiji only has CRB-S present in the country. The three countries were selected because they provided variation in their status of CRB and allowed for reliable comparisons of the damage scales under investigation to be tested. Sites covered within each country include Honiara, Tenaru, Henderson, West Guadalcanal and GPPOL (Guadalcanal plains palm oil limited) in the Solomon Islands. Kimbe, Port Moresby and Pacific Adventist University (PAU) in Papua New Guinea and between Nadi and Suva on Viti Levu, Fiji.

3.3 Data and data collection method

The study had two sets of data that were collected from different sources. The first set of data was from a secondary source that included photographs from a historical collection from CRB studies done over the years. The photographs consisted of undamaged to varying damage levels of CRB attacks on coconut palms from a collection of CRB work in Solomon Islands, Papua New Guinea and Fiji. The photo database was separated into two separate groups, primary dataset and validation dataset.

The primary dataset consisted of 1217 photographs from the Solomon Islands, PNG and Fiji in 2018. This group of photographs were used as part of the study’s initial photo database assessment to assess the performance of the three scales. Relative to the photographs in the primary dataset, a set of photographs taken in 2020 from the Solomon Islands were set aside as the validation dataset. The validation dataset was used to assess the performance of the scales in monitoring and detecting any change that may have occurred over a period of 2 years. A total of 1272 photographs with good image quality were selected from the database for the purpose of this investigation and any image with poor quality, blurred or obscured were eliminated from the process and not graded.

The second set of data, was gathered through an online survey consisting of a 4-part multiple-choice questionnaire and some demographic questions. The online survey was administered through a link generated from Qualtrics (see appendix for a copy of the survey) and was distributed via email using various professional networks. The survey ran over a period of one month and survey responses were monitored and collated in the Qualtrics software and further summarized and analysed using Microsoft Excel and Minitab, respectively.

3.3.1 Photo database assessment

From the photo database collection, 2349 palms in the primary dataset and 120 palms from the validation dataset, were identified as the suitable sample population and assessed and graded according to the damage levels observed on the fronds (see link for damage scores for the palms in the photo database https://doi.org/10.25400/lincolnuninz.14527113.v1). I assessed each palm and graded using the binary, 3-point and 5-point damage assessment scales. Some photographs had clusters of palms and where this situation was apparent, coconut palms were labelled and then assessed individually. The concept of the scales used for this study was adopted from previous studies carried out by Bedford (1980), Young (1975), Ero (2015), Jackson et al (2020) and Vaqalo et al. (2017), who all used damage assessment scales to determine severity levels of CRB infested palms.

Firstly, the photographs were arranged into the respective country folders then further subdivided into localities using Picasa 3. This folder arrangement was helpful and structured the approach for the photo assessment and grading. The photographs were viewed on a computer in their respective folders and then graded. Every palm that was suitable for grading was assessed and first categorised to the damage level represented on the binary scale (Figure 3-1) then the process was repeated for both the 3-point (Figure 3-2) and 5-point scales (Figure 3-3) separately.

Grade and Scale Description	
1	**2**
	
No CRB damage symptoms evident	CRB damage symptoms present

Figure 3-1: Binary Damage Scale

Grade and Scale Description		
1	**2**	**3**
		
No CRB damage symptoms evident.	Multiple fronds affected. Notching and breakage.	Non-recoverable. Palm dead or with growing point destroyed.

Figure 3-2: 3-point Damage Scale

Grade and Scale Description				
1	**2**	**3**	**4**	**5**
				
No CRB damage symptom evident	**Light**-light damage. Notching or tip damage. <20% frond loss.	**Medium**-Multiple fronds affected. Notching and breakage. 20%-50% frond loss.	**High**- Multiple fronds affected. Notching and breakage. >50% frond loss, but recoverable and not dead.	Non-recoverable. Palm dead or with the growing point destroyed.

Figure 3-3: 5-point Damage Scale

For the binary scale assessment, palms were categorised as either no damage or damaged. The grading for the 3-point damage scale was slightly different; palms were graded as no damage if there were no CRB damage symptoms observed and damaged if damage symptoms were present. If the palms were non-recoverable and with the growing point destroyed, they were graded as dead. The 5-point damage scale consisted of 5 distinct levels of damage categories beginning with no damage as the lowest category. Any palm that was observed with CRB damage symptoms was categorised according to the damage level displayed on the palm crown. If the damage displayed was less than 20% then grading of 2 was given. Grade 3 was given to palms with medium damage with multiple frond defoliation between the ranges of 21% and 50% and any damage that was above 50% with the growing point still present and palm not dead was graded as 4. Any palm that was detected as non-recoverable with the growing point destroyed was graded 5 which interpreted as dead on the 5-point damage scale. The damage grades from the three different damage scales were collated and summarised using Microsoft Excel.

The photo database was also used in an assimilation study to test the effect of detectable sample sizes using the datasets from Henderson in January, 2018 and Solomon Islands in February 2020. Sample sizes ranging from 100, 90, 75 and 50 undamaged palms were selected randomly from the Henderson and Solomon Islands dataset using a random number generator and graded accordingly using the 3 damage scales for this purpose.

3.3.2 Online Survey

The online survey (Appendix A) used digital photos of CRB affected coconut palms taken in the Solomon Islands over the past 2 years. Twenty individual standard palm pictures with a representation of damage from none to palms killed by CRB activity were selected by the research panel (Balanama Asigau, Sarah Mansfield, Mike Bowie, Trevor Jackson) for the survey, with 4 palms representing each category of the 5-point scale. This ensured that the spectrum of CRB damage was represented equally. These 20 standard pictures were incorporated into a 4-part multiple-choice questionnaire that included some general demographic questions in the latter part of the questionnaire. The first 2 pages of the survey questionnaire consisted of information about the research, the intent of the survey, the use of the survey results and a consent form to give respondents the choice to participate or not. Participation in the survey was entirely voluntary and the survey was designed to record data only if consent was given. The main body of the survey consisted of three sections and each section was made up of 20 questions. In these sections, respondents were required to grade the level of damage on the 20 randomly presented palm pictures using the binary, 3-point and 5-point damage scales. At the beginning of every section, respondents were provided with an instruction guide on the use of the three different scales and their respective grading categories. The survey then progressed on to the assessment and grading of the palms beginning with the binary assessment in the first section, followed by the 3-point assessment and then the 5-point assessment. The concluding section of the survey questionnaire included some general demographic questions including age group, gender, profession, place of residence and several specific questions relating to CRB, for example, experience level and years of experience with coconut and coconut pests. Respondents were asked to select a pre-determined experience range ranging between less than 2 years to more than 20 years in this field however if a respondent had no knowledge or experience with coconuts or coconut pests, they were asked to include how they had come to know of CRB and if the survey was their primary source of awareness for the invasive beetle.

3.4 Statistical analysis

All the data for this study were collated and summarised using Microsoft Excel and further tested and analysed with Qualtrics and Minitab 18. For the photo database assessment, two-way proportion tests on Minitab 18 were used for all the comparisons within and between each of the different scales. The same test was also carried out to compare between scale performance in the three study sites, to compare between the primary dataset and the validation dataset and also for the determination of the effect of a detectable sample size.

The online survey results were coded in Qualtrics then exported to Microsoft Excel. The data was then analysed in Minitab 18. Again, two-way proportion tests were conducted to make comparisons for each scale's performance and the influence of the explanatory variables.

3.5 Human ethics consideration

To administer an online survey questionnaire the approval of the human ethics committee in Lincoln University was essential. This process was to ensure the questionnaire administered adhered to the ethical standards of the university. Therefore, an application was lodged through a formal letter and a copy of the questionnaire was attached and sent to the Human Ethics Committee for their perusal. Approval for application No: 2020-41 was given on the 12th of October 2020 with the recommendation that a report is presented to the Human Ethics Committee after the study programme finishes, stating the ethics standards were complied with and upheld.

Chapter 4

Results

4.1 Introduction

This chapter sets out the results of the study. Here the findings of the study are presented objectively in relation to the research questions that the study sought to investigate. The study aimed to examine the potential of the binary, 3-point and 5-point scale in identifying damage intensity and changes over time and also to determine whether certain assessor's characteristics affected the accuracy of the damage scales.

4.2 Photo Database Assessment

4.2.1 Primary photo dataset

Comparison of undamaged palm proportions

For the first test, undamaged palm proportions from each study site were compared between the three different scales, then the proportions of undamaged palms in each scale and country were compared against each other. Further tests to assess the potential of the scales were drawn from comparing the proportion of undamaged palms in two localities Henderson and GPPOL in the Solomon Islands. The comparisons for these sites were done against two different periods, January and November 2018, to establish if changes in that period could be reflected by the scales and whether the scales worked consistently to identify these changes.

Comparison of palms between scales

Results from the comparison of undamaged palms between the different scales appeared similar for each individual country (Figure 4-1). A two proportion test was conducted using the undamaged palm counts from each scale to compare the proportion of undamaged palms pairwise. The different scales performed similarly except the comparison between the 3-point and 5-point scales in the Solomon Islands, where the 5-point scale identified approximately 2% fewer undamaged palms than the 3-point scale ($P= 0.010$).

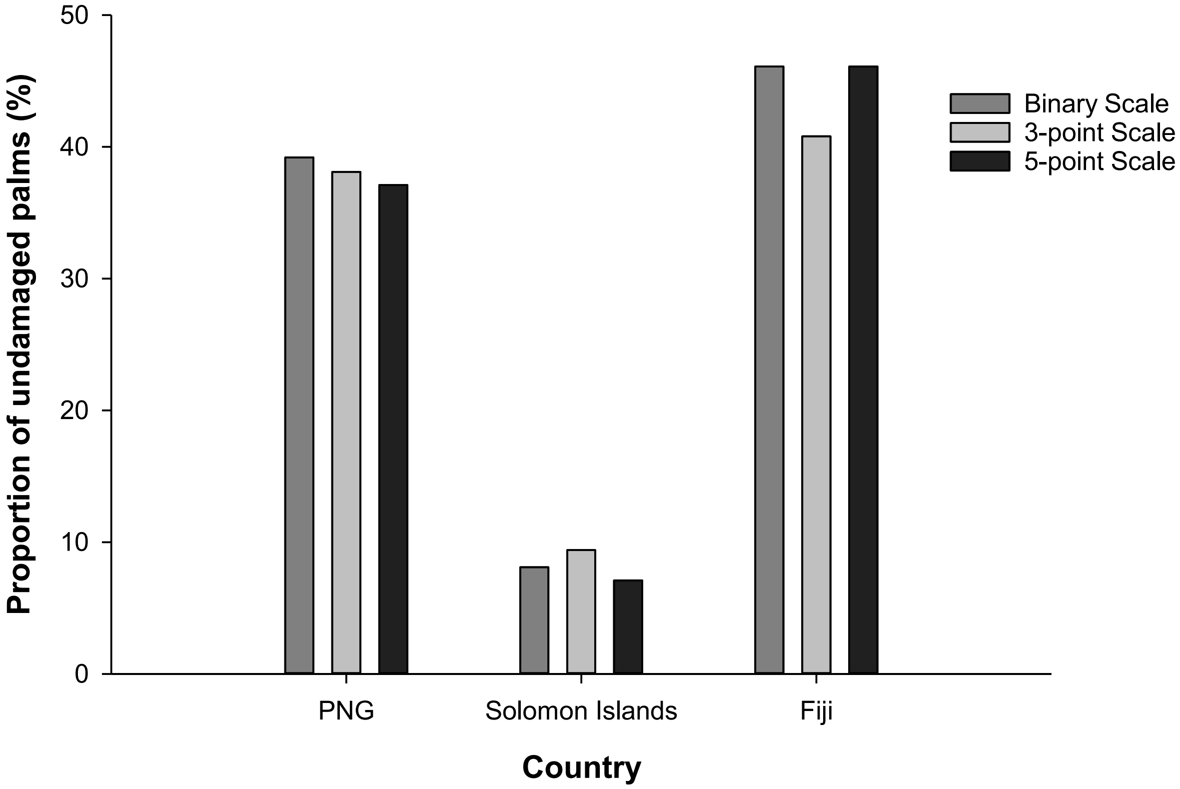


Figure 4-1: Comparison of undamaged palm proportions in the binary, 3-point and 5-point scales within PNG, SI and Fiji.

Comparison of scales between countries

For the comparisons of undamaged palms between countries, both PNG and Fiji have a high number of undamaged palms as compared to SI (Figure 4-2). A two proportion test was conducted to compare the proportion of undamaged palms between the three different countries and the results showed the differences in the proportion of undamaged palms between PNG and SI at 31.1% (P=<0.001), 28.7% (P=<0.001) and 30% (P=<0.001) in the binary, 3-point and 5-point respectively were statistically significant. The results also indicated that the differences in the proportion of undamaged palms at 38% (P= <0.001), 31.4% (P= <0.001) and 39% (P= <0.001) for the binary, 3-point and 5-point scales respectively between Fiji and SI were statistically significant. The results of the comparisons of the undamaged palms in the different countries was seen consistent among the three scales.

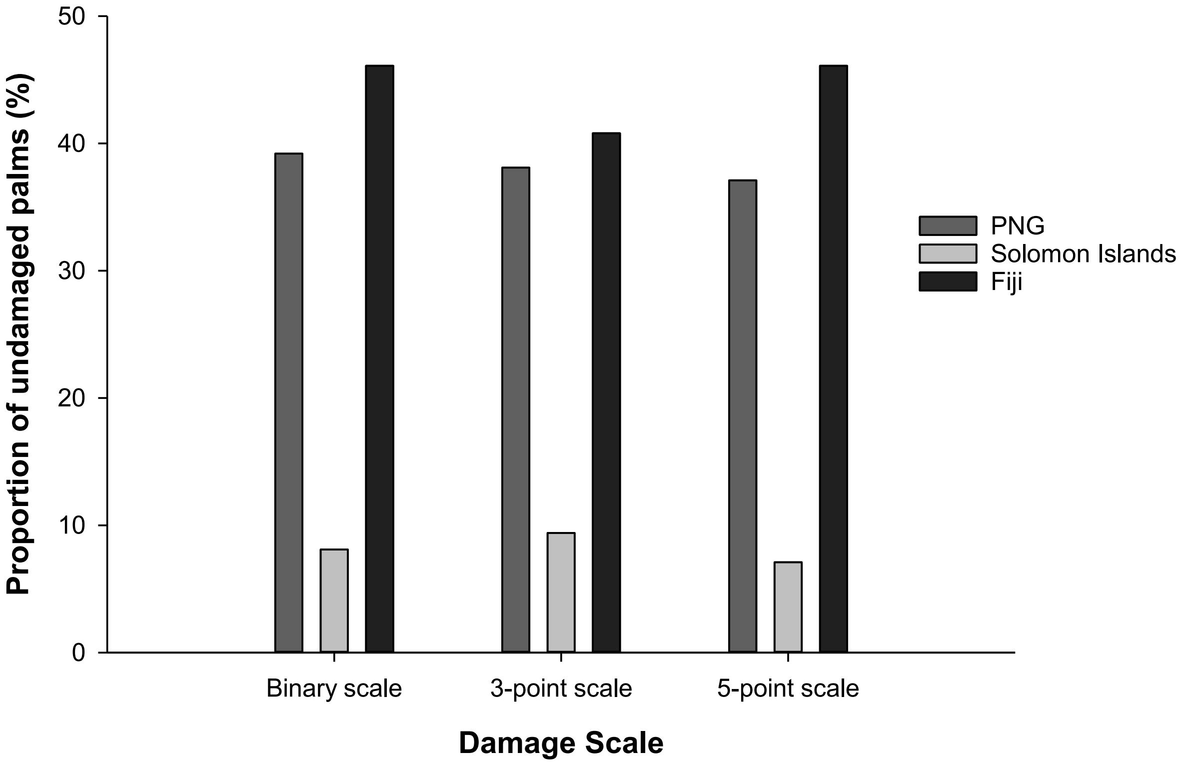


Figure 4-2: Comparison of undamaged palm proportions in the binary, 3-point and 5-point scale between PNG, SI and Fiji.

Comparison of scales in Henderson and GPPOL, the Solomon Islands between January and November 2018.

The comparison for differences in undamaged palm proportions in the two localities Henderson and GPPOL for January and November were not statistically significant between the three scales. Both places displayed low and almost similar undamaged palm percentages in all three scales for the month of January and November 2018 (Figure 4-3 and 4-4).

For Henderson, there were no undamaged palms recorded for January but in November, approximately 2% more undamaged palms were identified by the binary and 3-point scales and 1% increase in the 5-point scale. For GPPOL, undamaged palm numbers had increased by 6 from January to November in the binary and 3-point scale and only 5 in the 5-point scale. A two proportion test was carried out to determine the proportion of undamaged palms in these two localities at the different periods but the differences in the proportion of undamaged palms between January and November were not statistically significant.

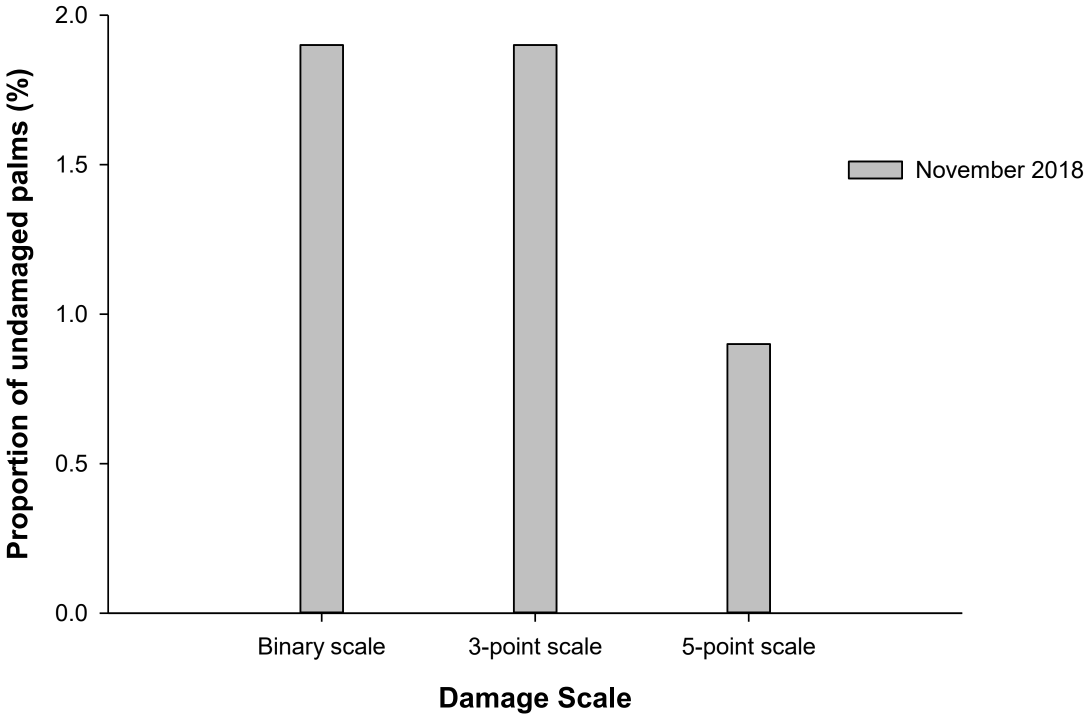


Figure 4-3: Comparison of undamaged palm proportions in the binary, 3-point and 5-point scale in Henderson in January and November, 2018.

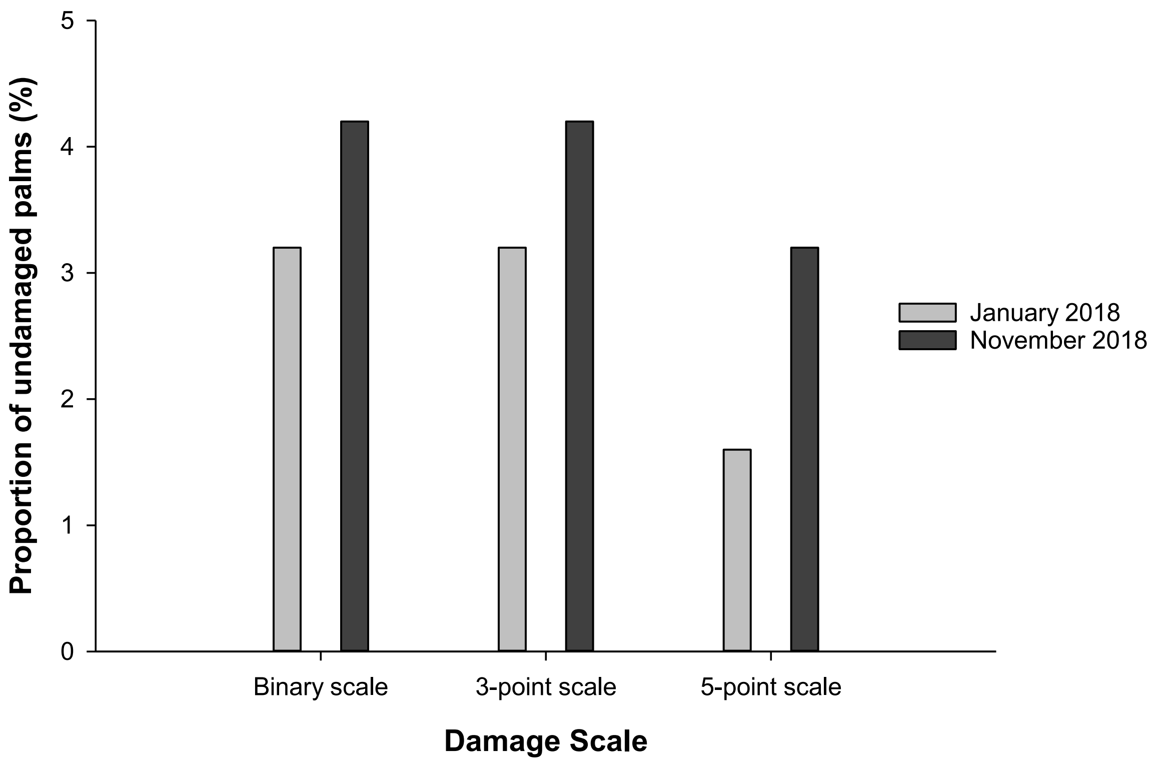


Figure 4-4: Comparison of undamaged palm proportions in the binary, 3-point and 5-point scale in GPPOL in January and November, 2018.

Comparison of dead palm proportions

The second test followed the same testing procedure except the number of dead palms in the multi-point scales were compared between scales and then between study sites and against different periods.

Comparison of dead palms between scales

The comparison of dead palms for PNG and Fiji were the same in the 3-point and 5-point damage scale but was different for the Solomon Islands as shown in Figure 4-5. A two proportion test was performed to compare the dead palm numbers pairwise and results for the comparisons showed the proportions of dead palms in PNG and Fiji were the same for both the 3-point and 5-point scale with 2.1% and 0.8% respectively but a 0.3% difference was identified between the scales for the Solomon Islands. These compared proportions of the dead palms in the two scales, however, were not statistically significant.

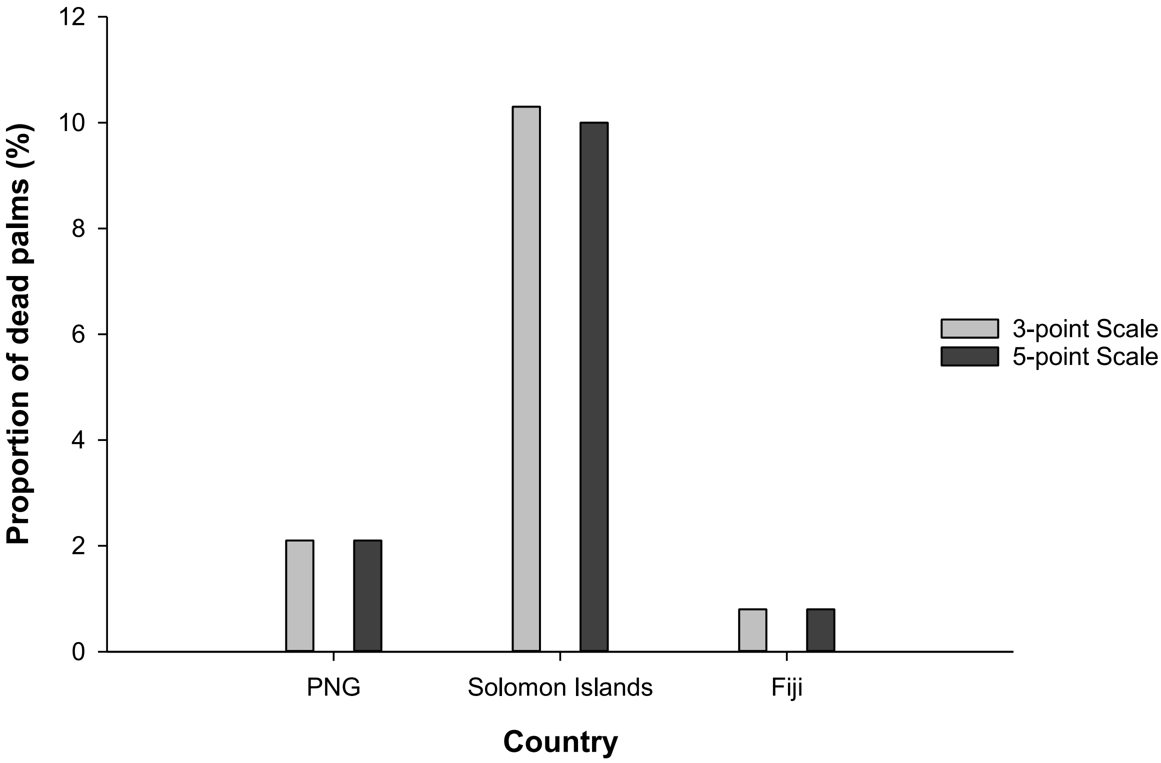


Figure 4-5: Comparison of dead palm proportions in the multi-point scales within PNG, SI and Fiji.

Comparison of scales between countries

The number of dead palms between countries was the highest in the Solomon Islands with 209 in the 3-point scale and 203 in the 5-point scale, while PNG and Fiji had the same number of dead palms in the two multi-point scales (Figure 4-6). The two proportion tests result for the comparison of these dead palm numbers for the scales between the countries showed that the differences in the number of dead palms by 8.2% ($P= <0.005$) and 7.9% ($P= <0.005$) between PNG vs SI and 9.5% ($P= <0.001$) and

9.2% (P= <0.001) between Fiji vs SI in the 3-point and 5-point scales respectively were statistically significant. The results also show that there was no statistical significance in the comparison of the proportion of dead palms between PNG and Fiji in both the 3-point and 5-point scales.

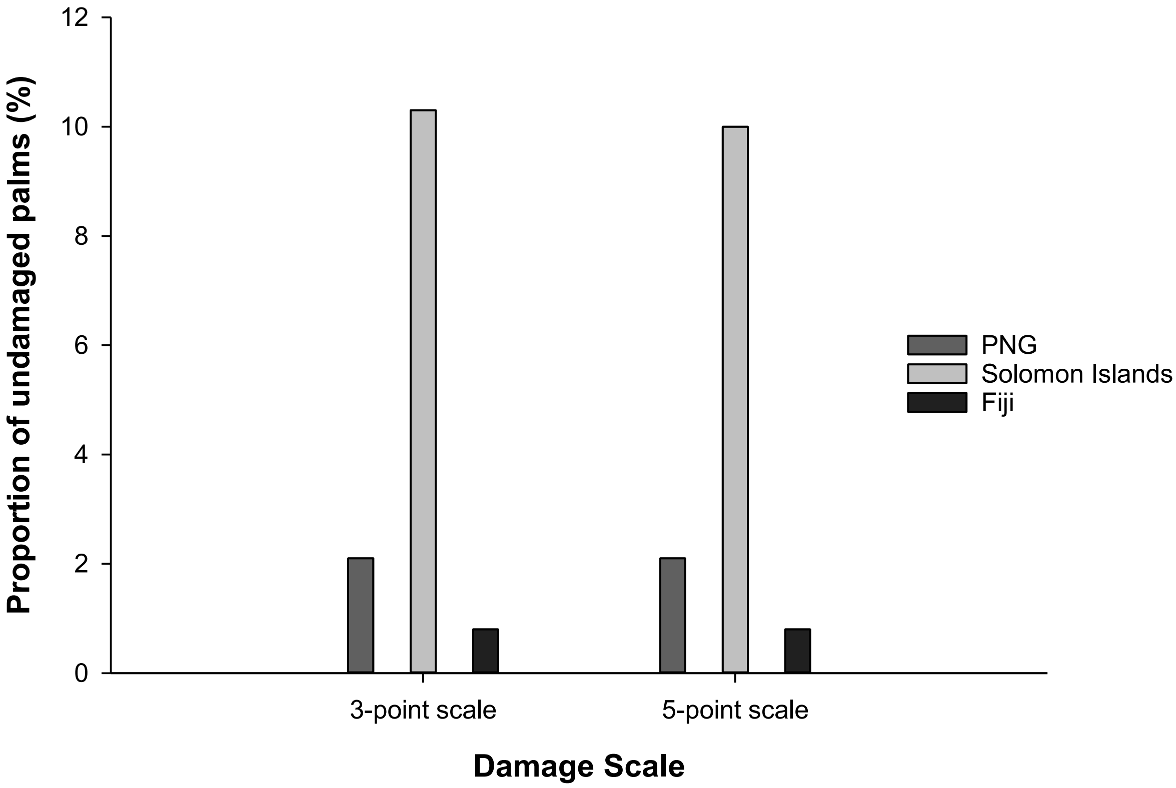


Figure 4-6: Comparison of dead palm proportions in the multi-point scales between PNG, SI and Fiji.

Comparison of scales in Henderson and GPPOL, the Solomon Islands between January and November 2018.

The proportion of dead palms had increased in the 3-point and 5-point damage scales by 10.5% and 4.8% for Henderson and 6.1% and 5% for GPPOL between January and November as seen in Figures 4-7 and 4-8. The results from the two proportion test carried out for the comparison of the number of dead palms for these localities were not statistically significant, indicating that the variations in the scales between January and November was not enough to detect a statistical significance from a sample size of 104 palms.

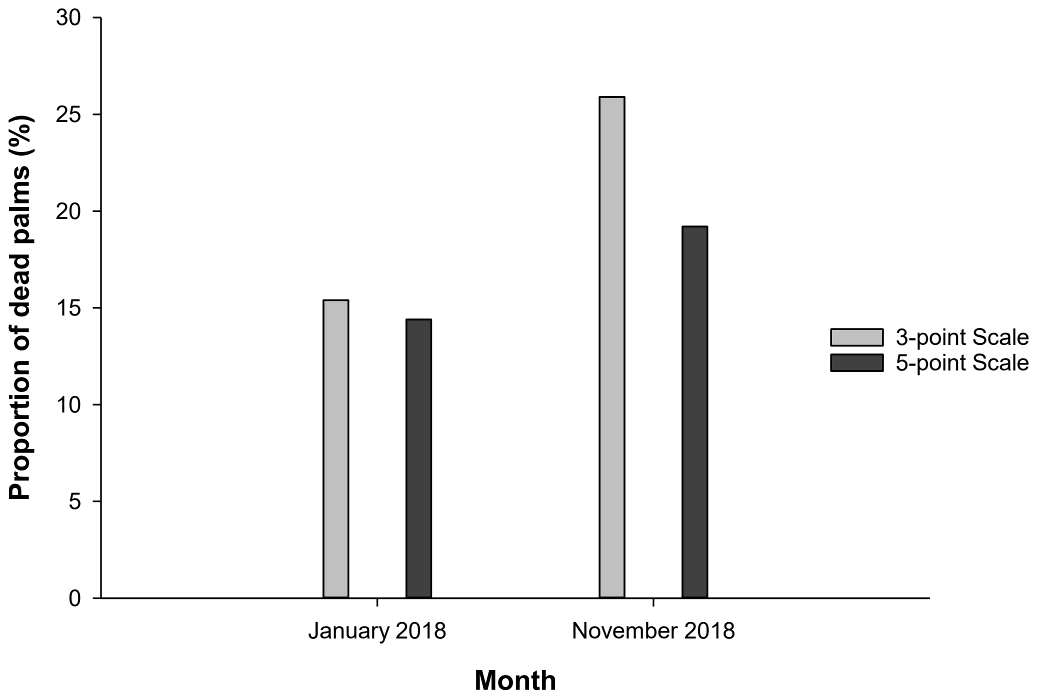


Figure 4-7: Comparison of dead palm proportions in the multi-point scales in Henderson in January and November, 2018.

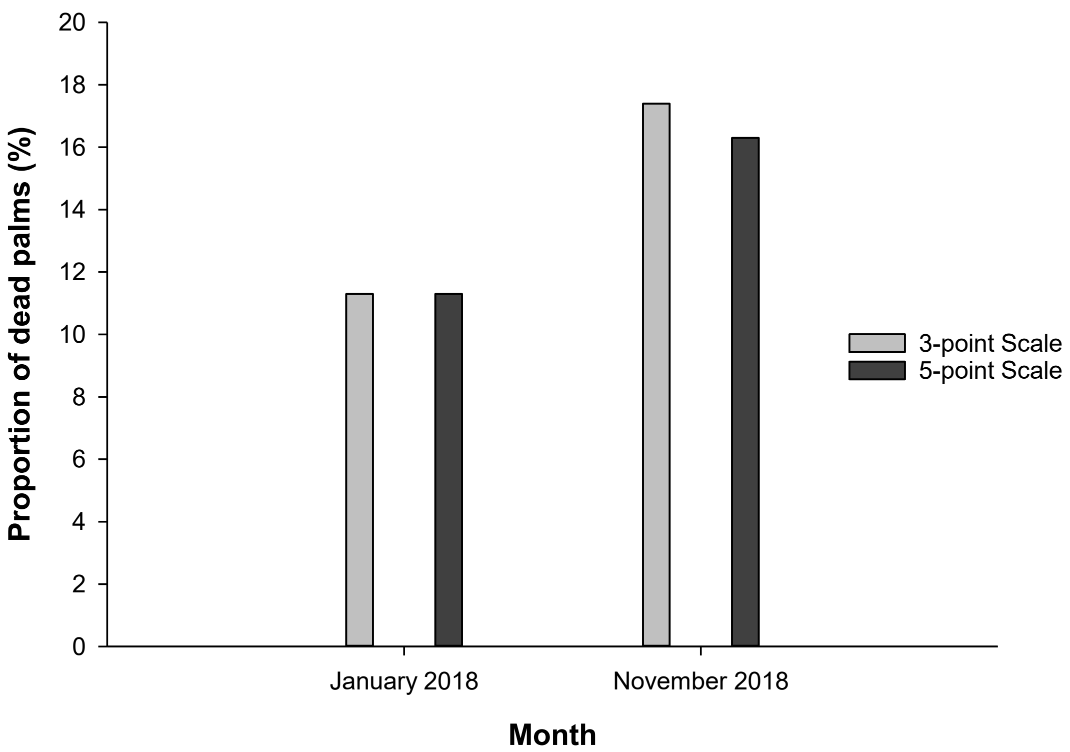


Figure 4-8: Comparison of dead palms in the multi-point scales in GPPOL in January and November, 2018.

4.2.2 Validation Dataset

The results displayed in this section are drawn from the validation dataset from the Solomon Islands in February 2020 and from the primary dataset for Henderson and GPPOL in the Solomon Islands in 2018. The same approach taken in comparing the scales and the scale's performance between the different study sites and time from the primary dataset were also applied for this dataset.

Comparison of undamaged palm proportions

The proportion of the undamaged palm numbers did not vary much between the three scales as they all performed similarly in identifying the undamaged palms (Figure 4-9). A two proportion test was done to make comparisons for the undamaged palm numbers between the scales, but the results showed no statistical significance in the proportions for undamaged palms.

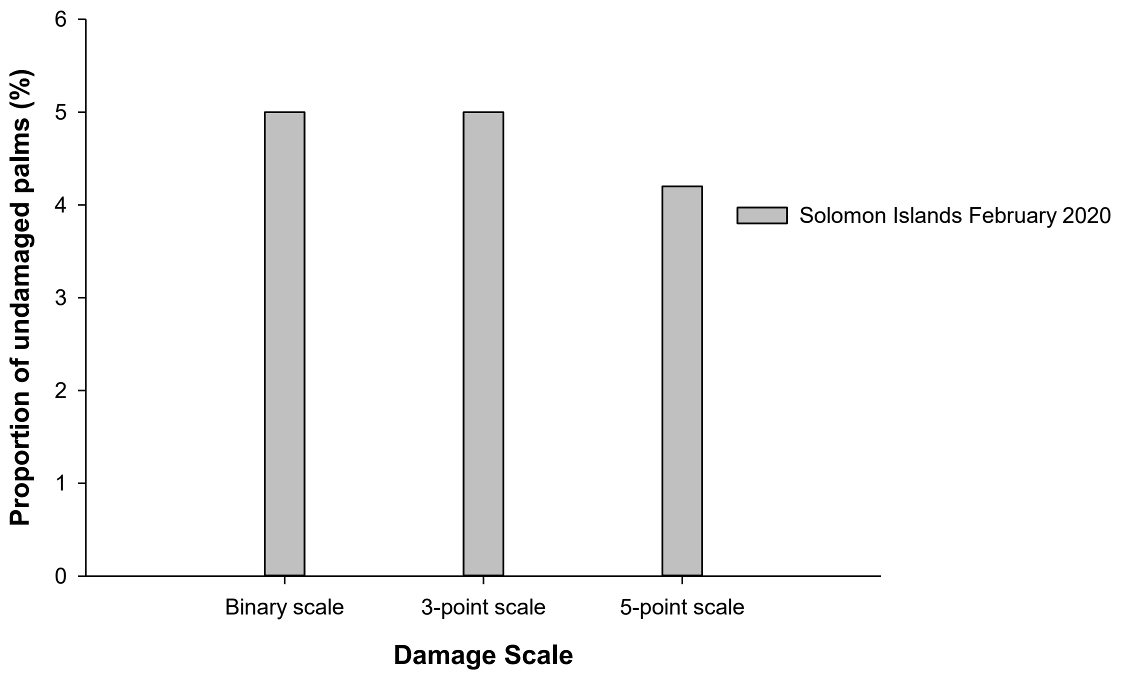


Figure 4-9: Comparison of undamaged palm proportions in Solomon Islands in February, 2020.

Comparison of the proportion of undamaged palms in the three scales between Henderson and GPPOL in January 2018 and Solomon Islands in February 2020.

Comparison for the proportion of undamaged palms over the longer timespan between Henderson in January 2018 and Solomon Islands in February 2020 shown in Figure 4-10 showed statistical significance in the binary (P= 0.032) and 3-point scale (P= 0.032). However, the results differed in the comparisons over the shorter timespan between Henderson in November 2018 and the Solomon Islands in January 2020 (Figure 4-11) with no statistical significance detected from the three scales. The results also showed that a change in 5% of the proportion of undamaged palms from a sample population of 104–120 palms and a timespan of two years was detectable in the binary and 3-point scale.

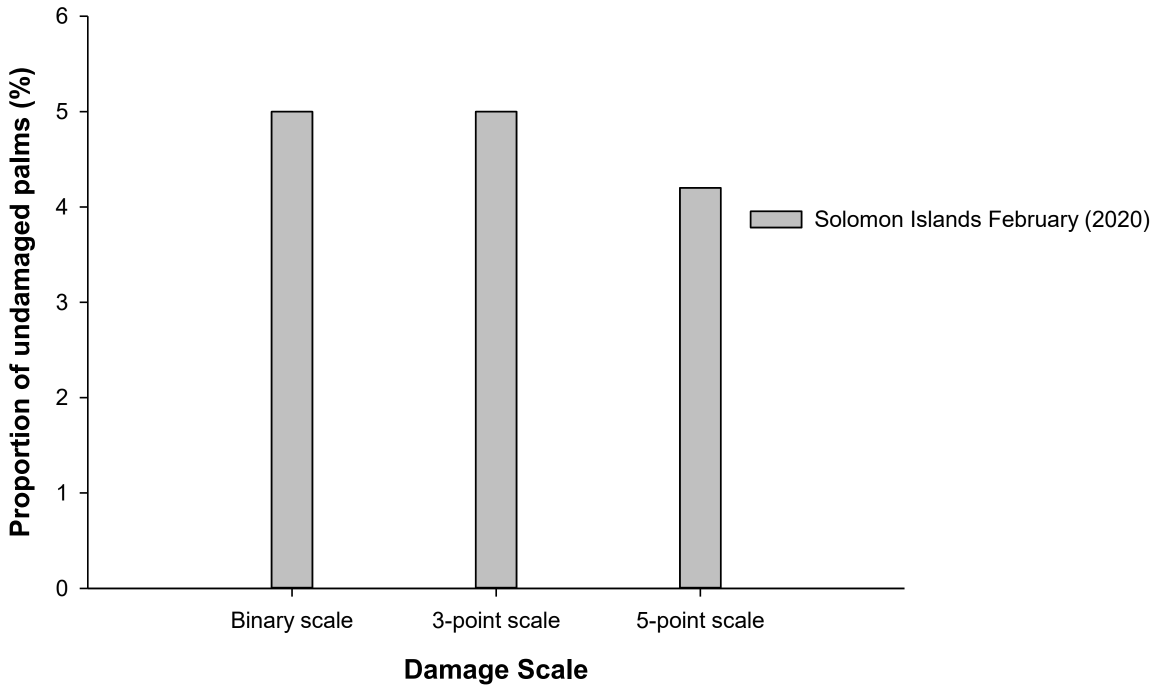


Figure 4-10: Comparison of undamaged palm proportions in the binary, 3-point and 5-point scales for Henderson in January, 2018 and Solomon Islands in November, 2020.

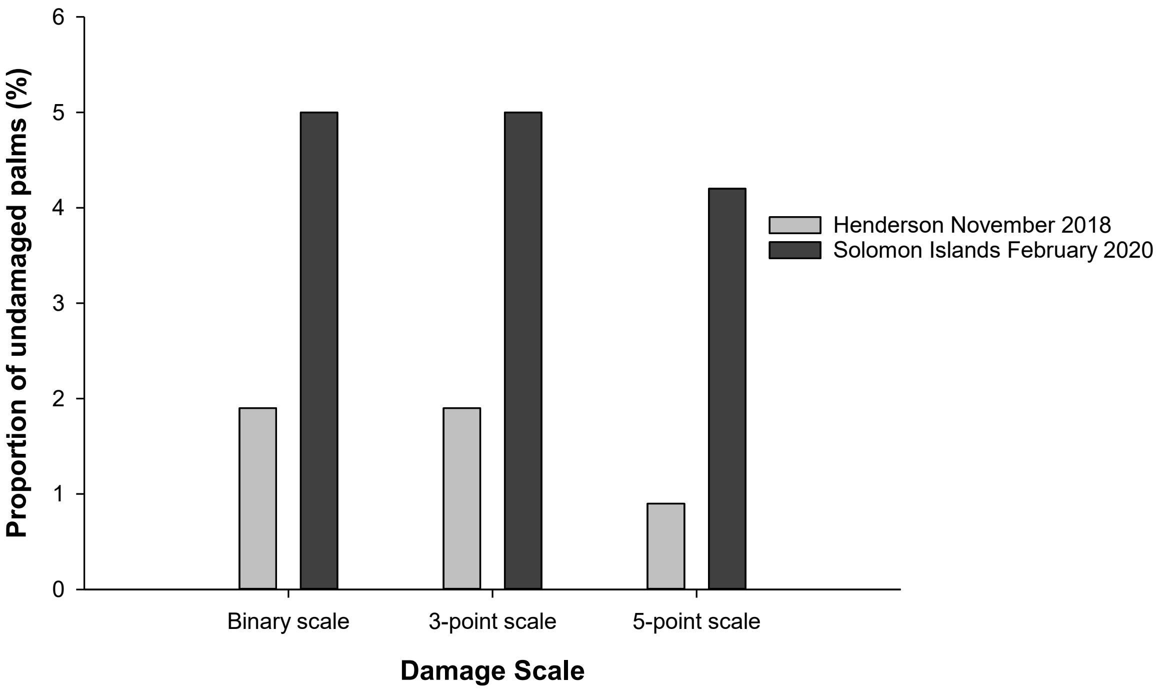


Figure 4-11: Comparison of undamaged palm proportions in the binary, 3-point and 5-point scale for Henderson in November, 2018 and Solomon Islands in February, 2020.

Comparison of the proportion of undamaged palms in the three scales between GPPOL in January and November 2018 and Solomon Islands in February 2020.

The comparison for the proportion of undamaged palms over a longer timespan between GPPOL in January 2018 and Solomon Islands in February 2020 and shorter timespan between GPPOL in November 2018 and Solomon Islands in February 2020 shown in Figure 4-12 and Figure 4-13 showed no statistical significance in the scales.

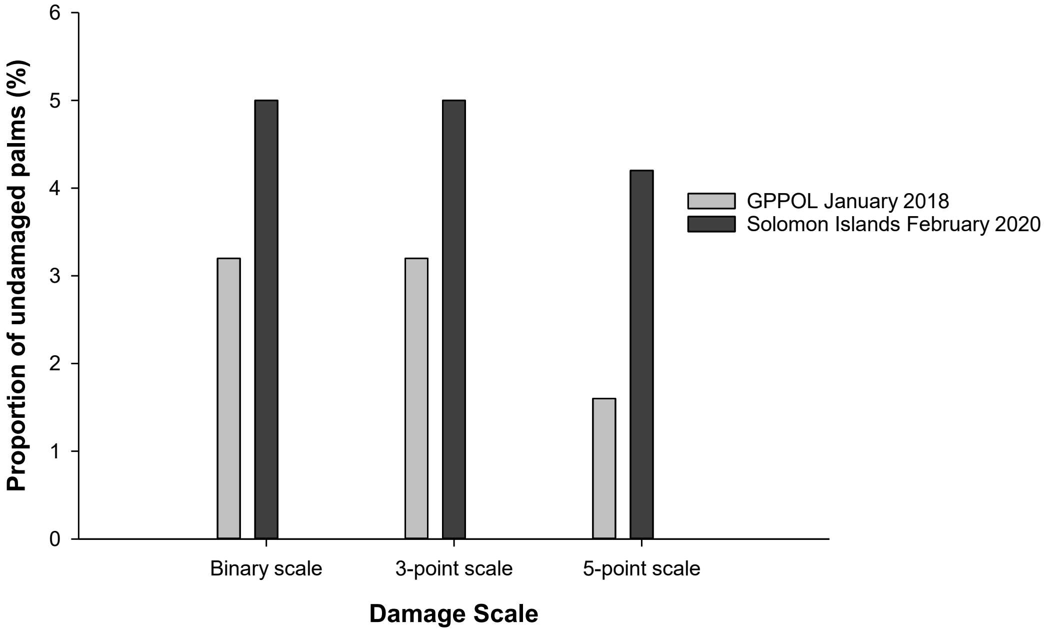


Figure 4-12: Comparison of undamaged palm proportions in the binary, 3-point and 5-point damage scales for GPPOL in January, 2018 and Solomon Islands in February, 2020.

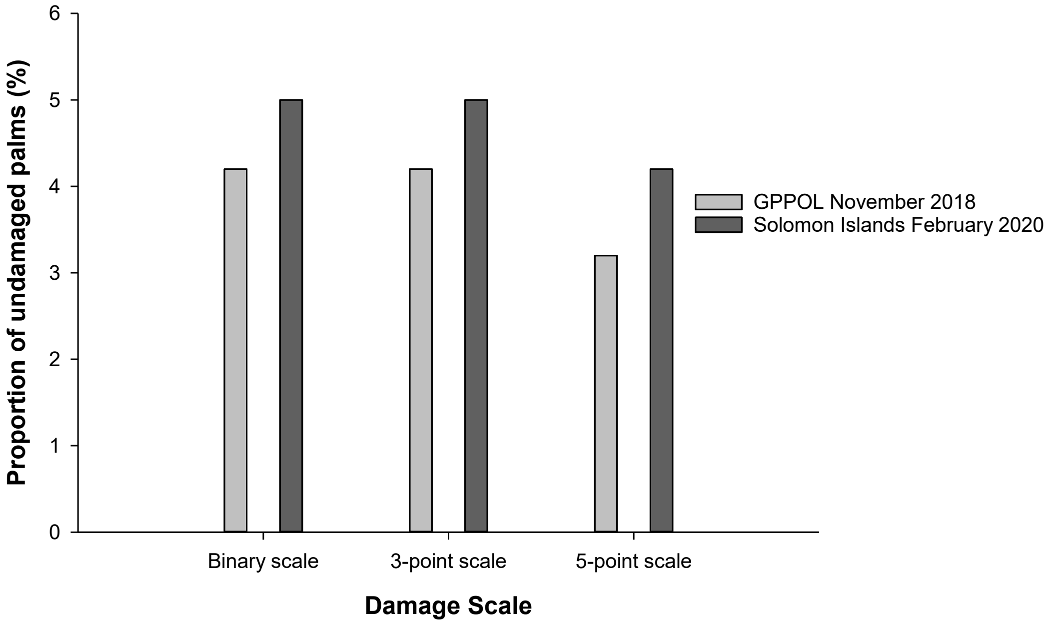


Figure 4-13: Comparison of undamaged palm proportions in the binary, 3-point and 5-point scales for GPPOL in November, 2018 and the Solomon Islands in February, 2020.

It was observed that a change in 2.6% of the proportion of undamaged palms from a sample population between 62–120 palms and a timespan of 2 years was not sufficient to detect any significant change in all scales. Likewise, a change in 1% of the proportion of undamaged palms in a shorter time span of 1 year was not statistically significant to detect any change from a sample population between 120–190 palms in all scales.

Comparison of dead palm proportions.

The comparison of the proportion of the dead palms in the Solomon Islands in February 2020 did not vary much between the multi-point scales with the 5-point scale identifying only 0.8% fewer dead palms than the 3-point scale (Figure 4-14). Two proportion test was performed on the numbers of dead palms in the 3-point and 5-point scale in the Solomon Islands in February 2020 to compare the proportions of dead palms in each multi-point scale. The results from this test showed no statistical significance in the variation of the dead palms in the 3-point and 5-point scale.

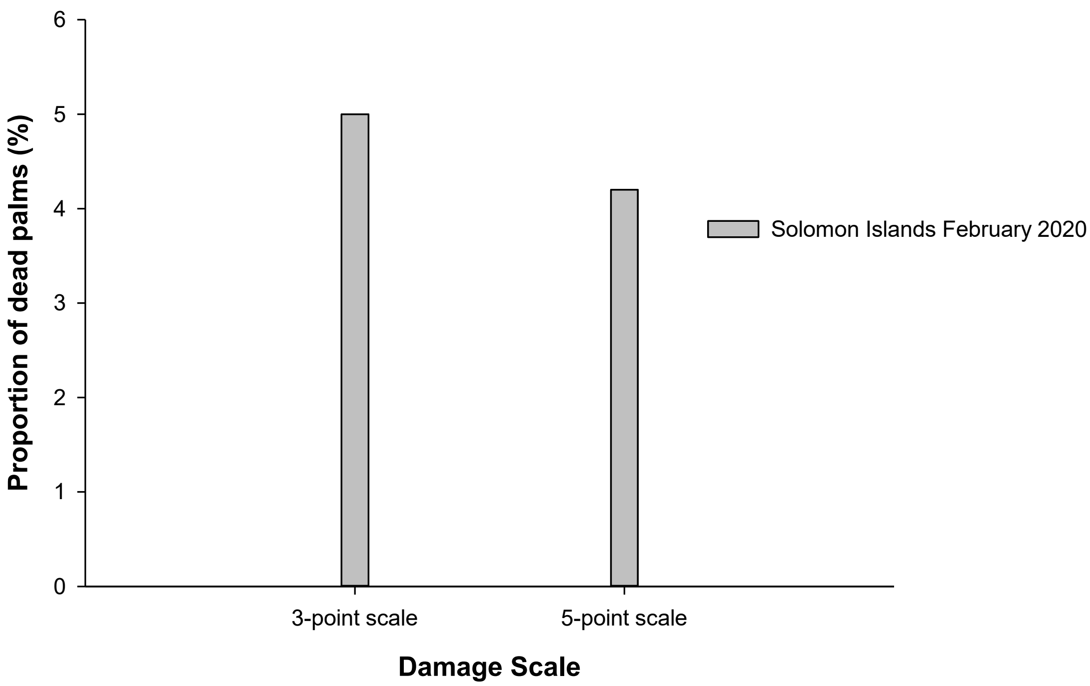


Figure 4-14: Comparison of dead palm proportions in the multi-point scales in the Solomon Islands in February 2020.

Comparison of the proportion of dead palms in the multi-point scales between Henderson in January and November in 2018 and the Solomon Islands in February 2020.

Comparison of dead palm proportions for Henderson in January 2018 against the Solomon Islands in February 2020 and Henderson in November 2018 against the Solomon Islands in February 2020 were statistically significant for both the 3-point and 5-point scale (Figure 4-15 and Figure 4-16). The results show that a reduction between 9.6% (P= 0.026) and 20.1% (P=<0.001) of dead palms in the 3-point scale and 8.6% (P=0.042) and 13.4% (P=0.003) in the 5-point scale are detectable in a sample size of 104 or more between approximately 1.5 years and 2.2 years.

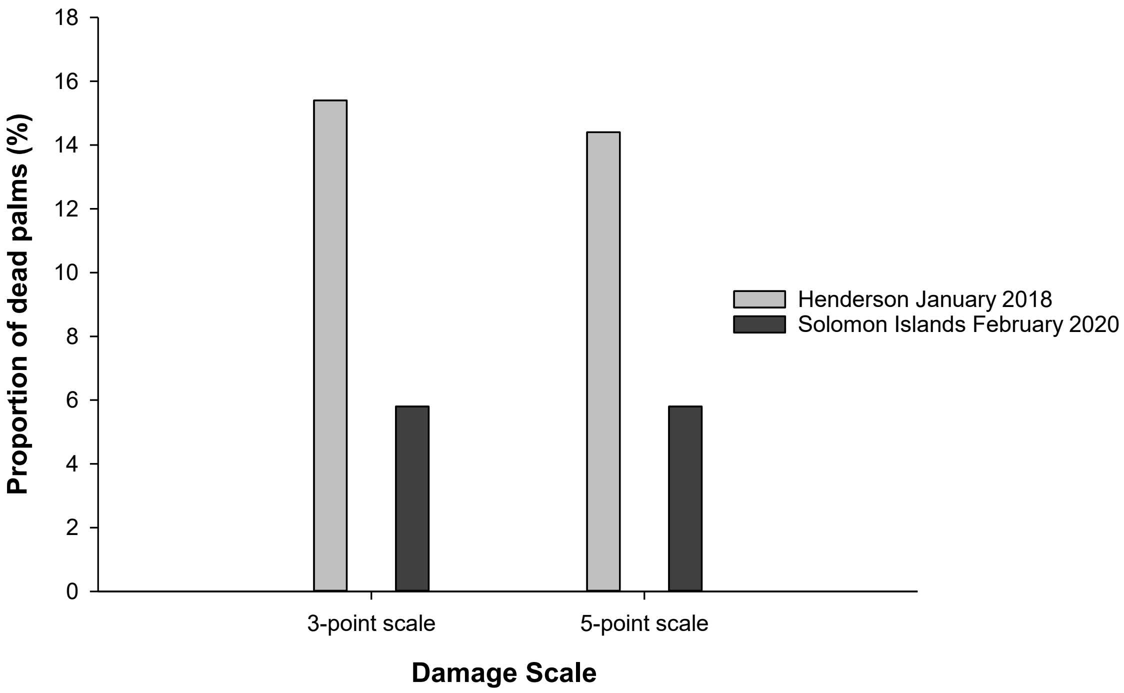


Figure 4-15: Comparison of the dead palm proportions in the multi-point scales for Henderson in January 2018 and the Solomon Islands in February 2020.

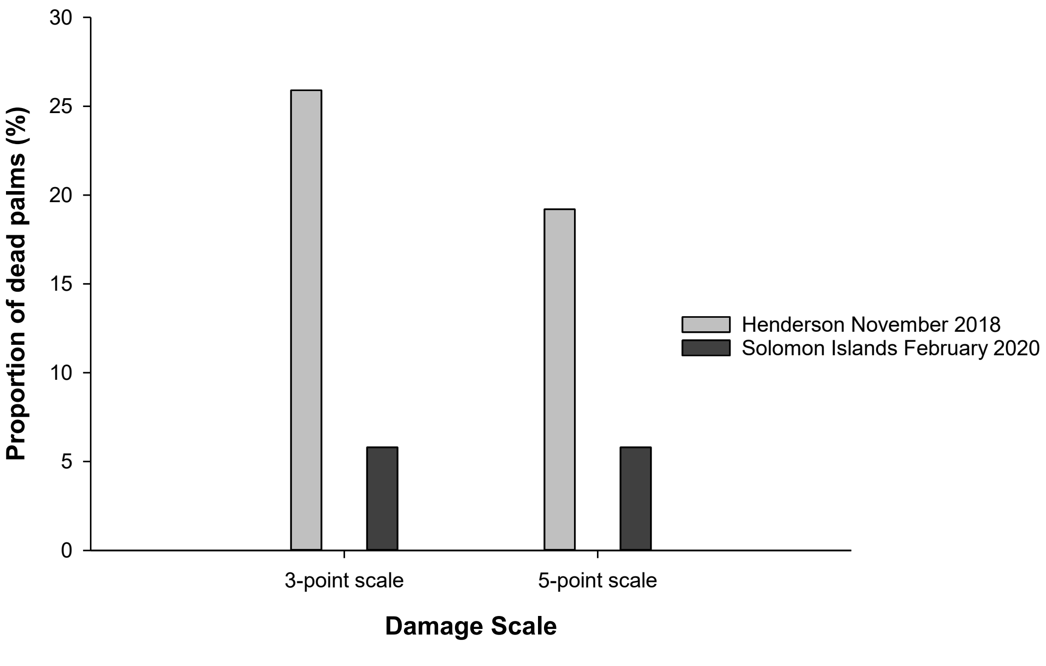


Figure 4-16: Comparison of the proportion of dead palms in the multi-point scales between Henderson in November, 2018 and the Solomon Islands in February, 2020.

Comparison of the proportion of dead palms in the multi-point scales between GPPOL in January and November in 2018 and the Solomon Islands in February 2020.

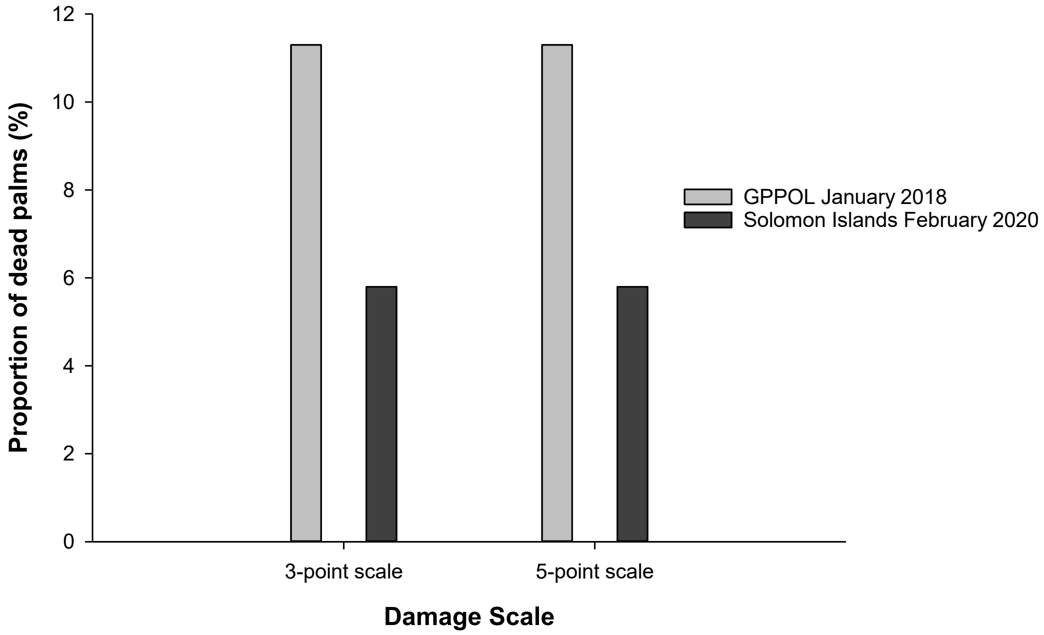


Figure 4-17: Comparison of the dead palm proportions in the multi-point scales for GPPOL in January 2018 and the Solomon Islands in February 2020.

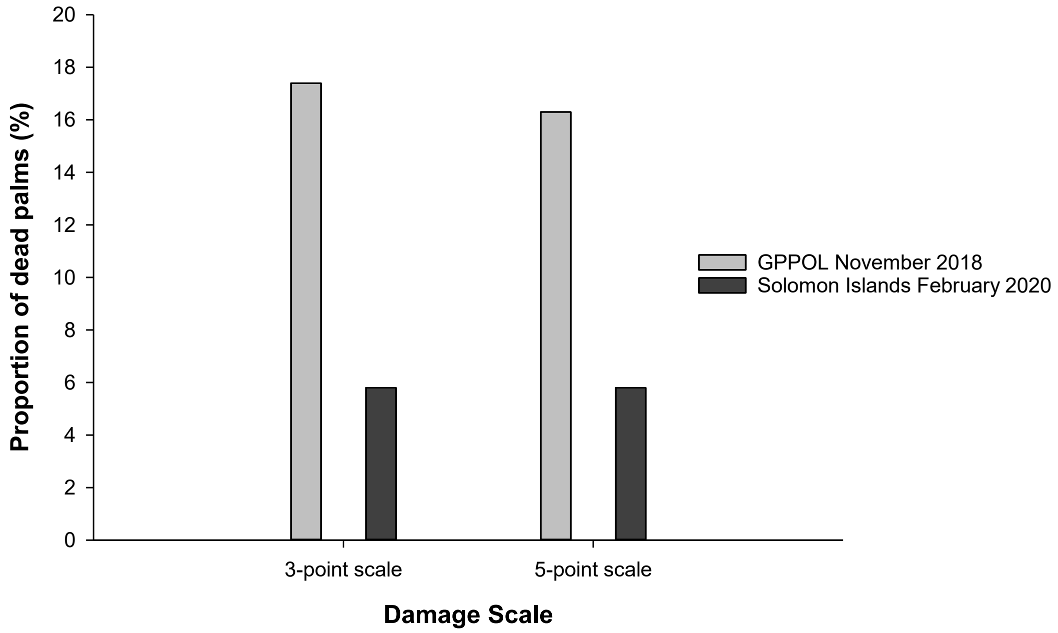


Figure 4-18: Comparison of dead palm proportions in the multi-point scales for GPPOL and the Solomon Islands in 2020.

The results from the comparisons on dead palm proportions between GPPOL in January 2018 vs the Solomon Islands in February 2020 seen in Figure 4-17 showed no statistical significance in both the 3-point and 5-point scale as compared to the comparison for the dead palms in GPPOL in November 2018 vs the Solomon Islands in February 2020 in Figure 4-18. The latter comparison showed that the difference of 11.6% (P= 0.003) and 10.5% (P= 0.007) reduction in the 3-point and 5-point scale respectively in the dead palms in GPPOL in November 2018 vs the Solomon Islands in February 2020 were statistically significant.

4.3 Testing the effect of detectable sample sizes.

Assimilation of varying sample sizes of undamaged palm proportions were trialled to identify the effect of a detectable sample size using the datasets from Henderson in January 2018 and the Solomon Islands in February 2020 (Table 4-1). Two proportion test was performed on the undamaged palm numbers for Henderson in January 2018 and the Solomon Islands in February 2020 to compare the proportion of undamaged palms in the three scales. The results showed that only a 6% change in the proportion of undamaged palms from a sample population of 100 palms in a 2-year timespan was statistically significant in the binary and 3-point scale.

Table 4-1: Assimilation results for sample sizes 100, 90, 75 and 50.

Sample Size	Scales	Henderson, Solomon Islands, January (2018)	Solomon Islands February (2020)	P-value
100	Binary	0 % (0/100)	6 % (6/100)	**0.029**
	3-point	0 % (0/100)	6 % (6/100)	**0.029**
	5-point	0 % (0/100)	5 % (5/100)	0.059
90	Binary	0 % (0/90)	3.3 % (3/90)	0.246
	3-point	0 % (0/90)	3.3 % (3/90)	0.246
	5-point	0 % (0/90)	3.3 % (3/90)	0.246
75	Binary	0 % (0/75)	5.3 % (3/75)	0.120
	3-point	0 % (0/75)	5.3% (3/75)	0.120
	5-point	0 % (0/75)	5.3 % (3/75)	0.120
50	Binary	0 % (0/50)	6 % (3/50)	0.242
	3-point	0 % (0/50)	6% (3/50)	0.242
	5-point	0 % (0/50)	6 % (3/50)	0.242

4.4 Online Survey

4.4.1 Population Description

The online survey had 371 respondents in total with 241 completed and 130 incomplete surveys. The incomplete surveys were eliminated and not used for the study. Over half of the respondents that participated in the survey were females (53%) with majority of respondents belonging to the age range between 31–40 years of age while those above 60 years of age formed the smallest respondent group. Respondents were asked to list their profession, 49% of the respondents identified themselves as scientists, 15% as students and 36% of the respondents' selected "others" which represented various professions ranging from social scientists, administrators, and laboratory and field technicians to accountants etc. People living in Australia and New Zealand (ANZ) made up the bulk of the respondents' population with 159 respondents, followed by the Pacific Islands including Papua New

Guinea and the Solomon Islands with 47 respondents. There were 9 respondents from the Asian region and 27 respondents identified their place of residence with a country other than ANZ, the Pacific or Asia. Some of the countries included in this category were South Africa, the USA, Ireland, Mexico and France.

Table 4-2: Survey population distribution

Gender		Age Group		Profession		Place of Residence	
Males	Females	18-30 years old	44 (18%)	Student	37 (15%)	Asia	9 (4%)
114	127	31-40 years old	66 (27%)	Scientist	118 (49%)	ANZ	159 (66%)
47%	53%	41-50 years old	56 (23%)	Other	86 (36%)	Pacific	47 (19%)
		51-60 years old	53 (22%)			Others	27 (11%)
		Above 60 years old	22 (9%)				

As indicated in Figure 4-19, 66 of the respondents, from the 241 respondents, had experience with working on coconuts or coconut pests. From this experienced population, the majority (41%) of the respondents only had less than 2 years of experience while 23% of the experienced respondents had 3-5 years of experience. The remaining proportion 36% of the experience category was divided evenly between 5-10 years, 10-20 years and more than 20 years of experience.

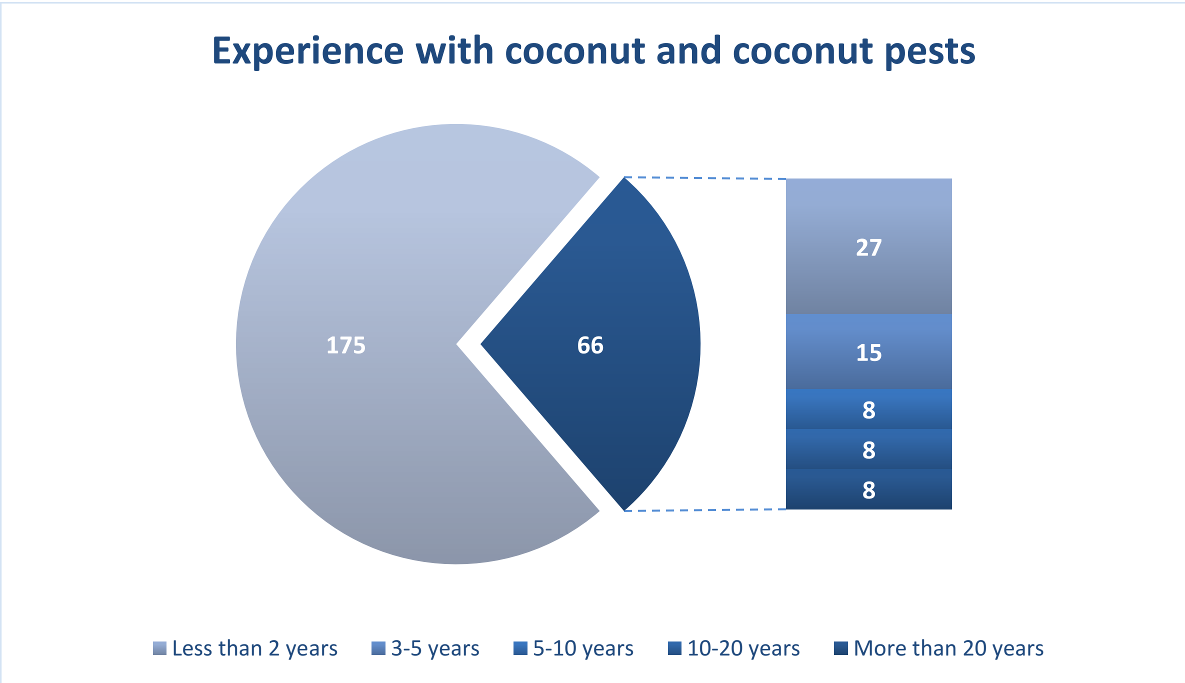


Figure 4-19: The proportion of "Experienced" respondents and their years of experience with coconut or coconut pests.

Figure 4-20 shows the 175 respondents that responded to having no experience with coconuts or coconut pests. Fifty-four percent of that population had prior knowledge of CRB before the survey. When asked about the source they acquired the CRB knowledge from, 27% of the population had known through their line of work, 12% from the internet, 10% from their university lecturer and 2% from their local DPI or MPI. About 47% of the respondents chose the "others" in the questionnaire which indicated they learnt of CRB from a source other than the 4 mentioned above. These sources include media announcements, from colleagues and family members that work in the coconut or CRB related projects, professional seminars and because it is a problem present in the place of residence.

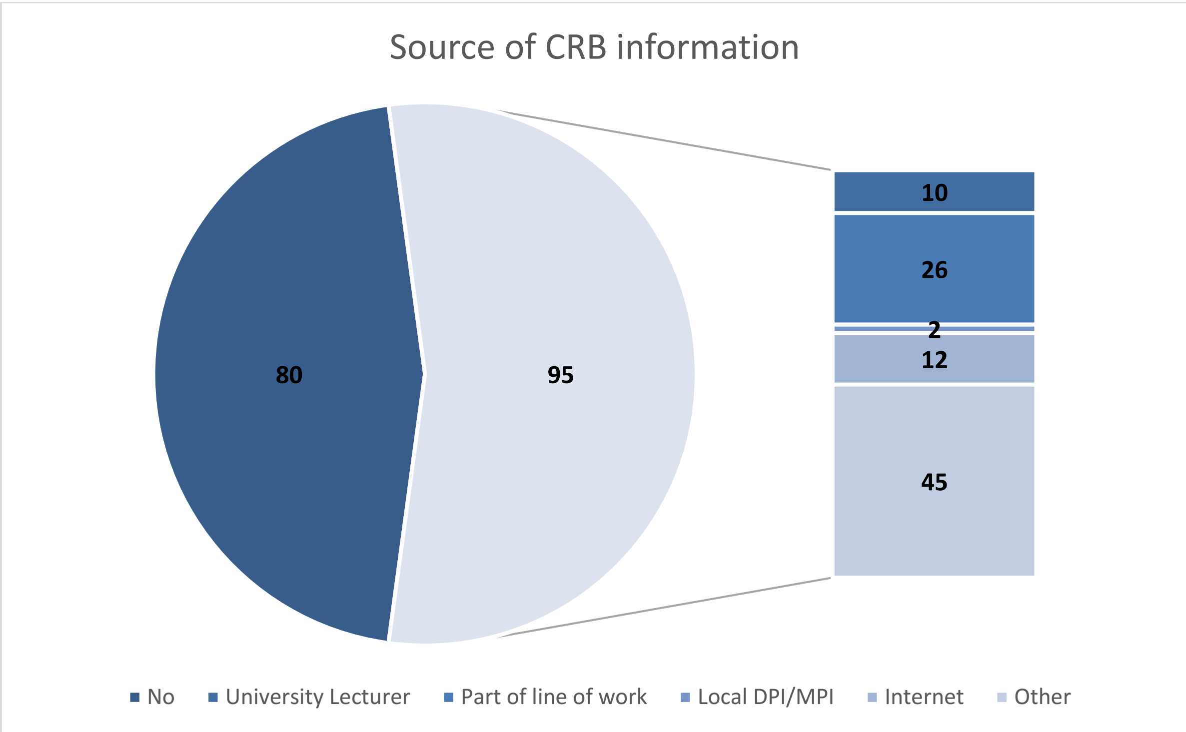


Figure 4-20: Response to source of CRB information from respondents who have not worked with coconut or coconut pests before.

4.4.2 Overall scale performance

Comparison of the scales as a whole.

The results here represent the performance of the scales as a whole. Correct answers show the number of people that answered/categorised all 20 palms in the respective scales correctly while Incorrect answers show the number of people that got at least one of the 20 palms wrongly categorized in a scale.

Two proportion test was performed to response numbers by scales to compare response numbers between the three scales pairwise. The differences in the correct and incorrect response answers in a scale between the scales showed statistical significance. Results showed that the binary scale had 12% (P= <0.001) more correct answers than the 3-point scale, and 21.9% more than the 5-point scale (P=

<0.001). The results for the comparison between the 3-point and 5-point showed that a 9.9% (P= <0.001) more correct answers in the 3-point as compared to the 5-point scale. It was also observed in Figure 4-21 that the number of correct answers for the scales as a whole reduced as the grades on the scale increased. Contrarily, the number of incorrect answers increased as the scales increased from a binary grading system to the 3-point then 5-point grading system.

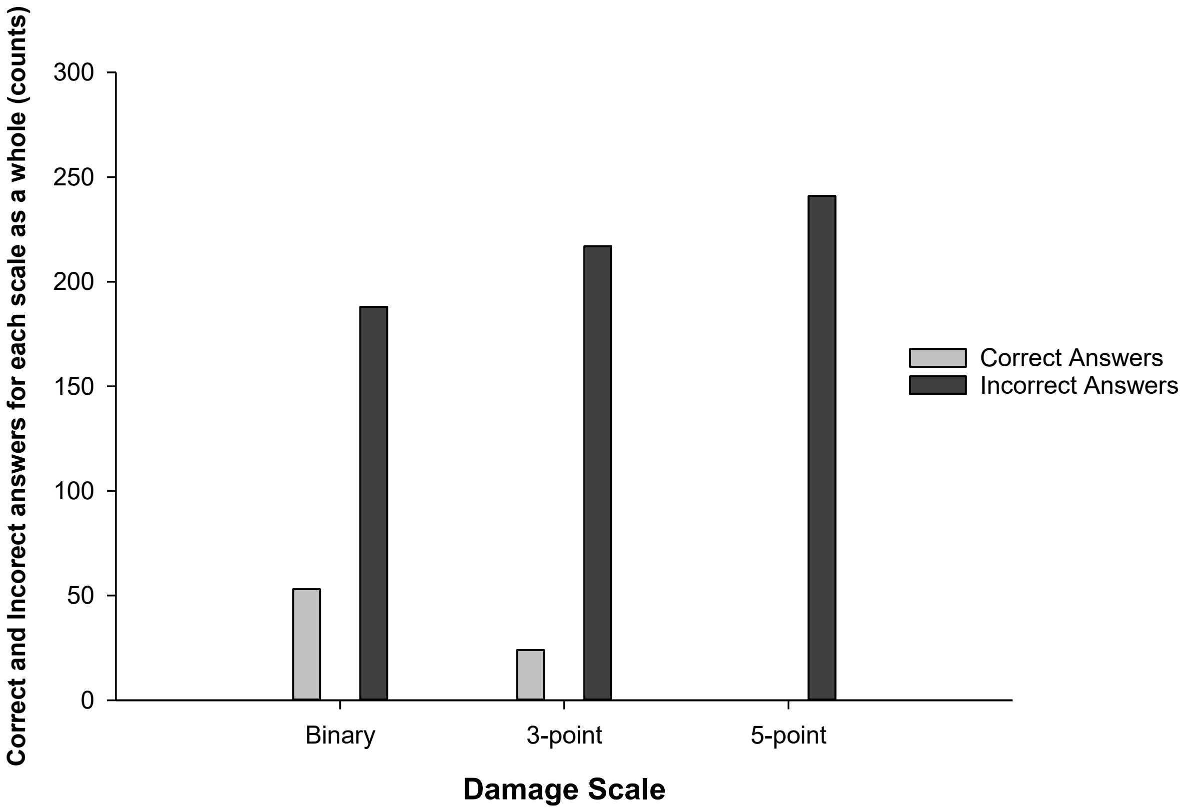


Figure 4-21: Correct and incorrect response numbers for each of the scales as a whole.

Comparison of individual responses within a scale.

For this comparison, correct and incorrect answers were recorded from the grading of the 20 palms by each respondent using the three different scales. So, in total, 60 responses were recorded per respondent in the survey.

The results show that the difference in the correct answers between scales was statistically significant for binary vs 5-point (P= <0.001) and 3-point vs 5-point (P= <0.001). This indicated that the correct answers in the binary (4037) and 3-point (4025) scales were significantly higher than the 5-point (3166) damage scale, inversely, the number of incorrect answers in the binary (783) and 3-point (795) damage scale was lower than the 5-point (1654) damage scale. From the results shown in Figure 4-22 the number of correct answers decreased as the grading scale increased while the number of incorrect answers increased as respondents moved up the grading scales. The results indicated that both the binary and 3-point scales performed similarly and there was not much variation in both the correct and incorrect answers between these scales.

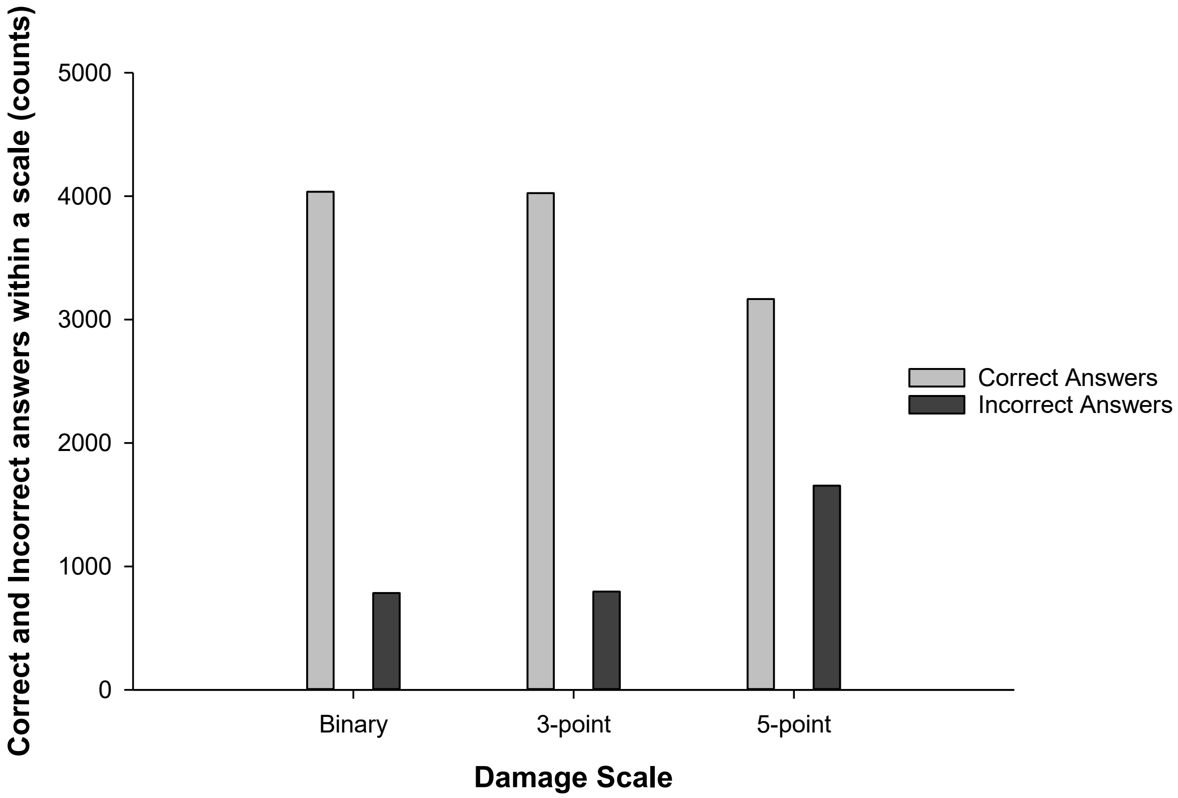


Figure 4-22: Correct and incorrect response numbers within each scale.

Comparison of responses for each category in the 3 different scales.

In this section palms in the same category in their respective damage scales were graphed together for comparisons.

1. No Damage

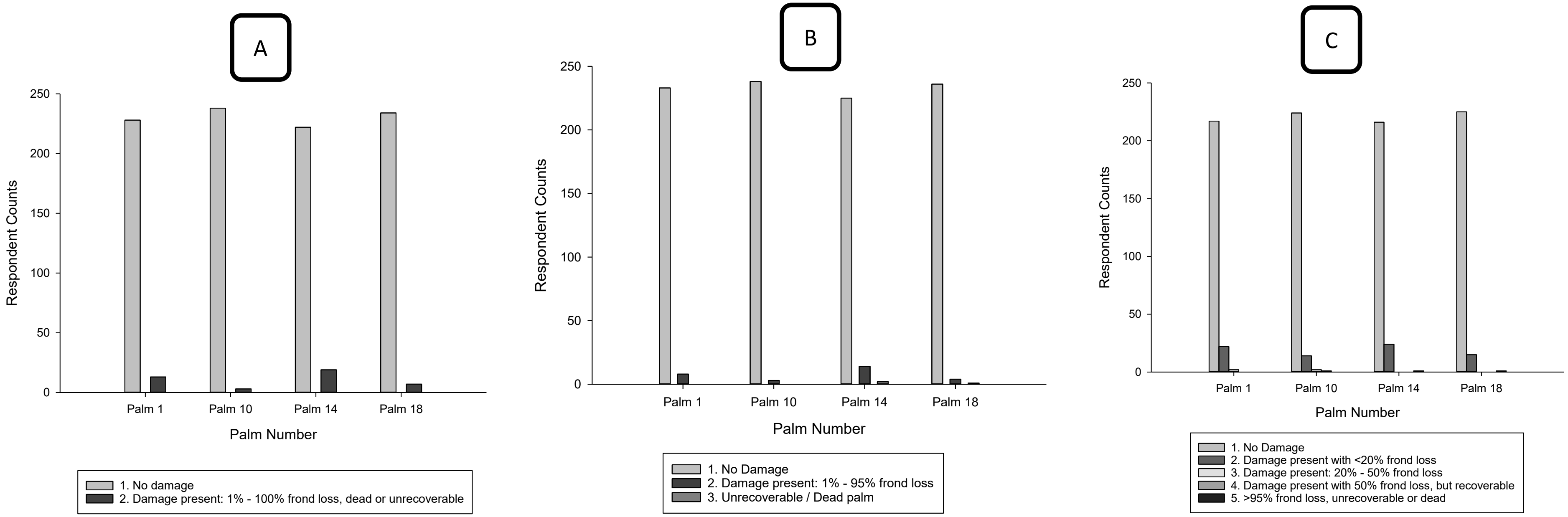


Figure 4-23: Damage grading for palms 1, 10, 14 and 18 A) Binary scale assessment, B) 3-point scale assessment and C) 5-point scale assessment.

Palms 1, 10, 14 and 18 in the survey were classified as: 1. No Damage. The majority of the respondents were able to grade the palms correctly in the binary, 3-point and 5-point damage scale (Figure 4-23 A, B & C).

2. Binary: Damage present: 1%–100% frond loss, dead or unrecoverable, 3-point: Damage present: 1%–95% frond loss, 5-point: Damage present with <20% frond loss.

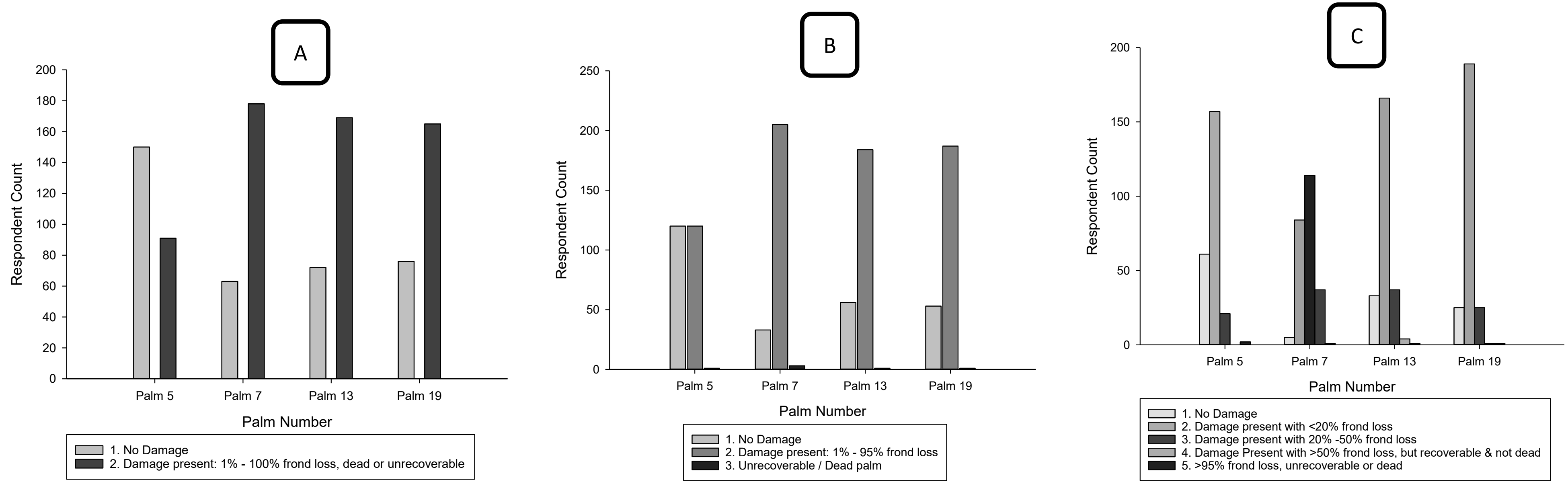


Figure 4-24: Damage grading for Palms 5, 7, 13 and 19. A) Binary scale assessment, B) 3-point scale assessment and C) 5-point scale assessment.

Palms 5, 7, 13 and 19 are in Category 2 represented as “Damage present: 1%–100% frond loss” in the binary scale and “Damage present: 1%–95% frond loss” in the 3-point scale and “Damage present with <20% frond loss" in the 5-point scale. According to the respondent's results (Figure 4-24 A, B & C), Palm 13 and Palm 19 were OK across the scales. Palm 5 came out badly on both the binary and 3-point scale but was OK on the 5-point scale. The grading of Palm 7 was OK for the binary and 3-point scale but poor on the 5-point scale.

3. Binary: Damage present: 1%–100% frond loss, dead or unrecoverable, 3-point: Damage present: 1%–95% frond loss, 5-point: Damage present with 20%–50% frond loss.

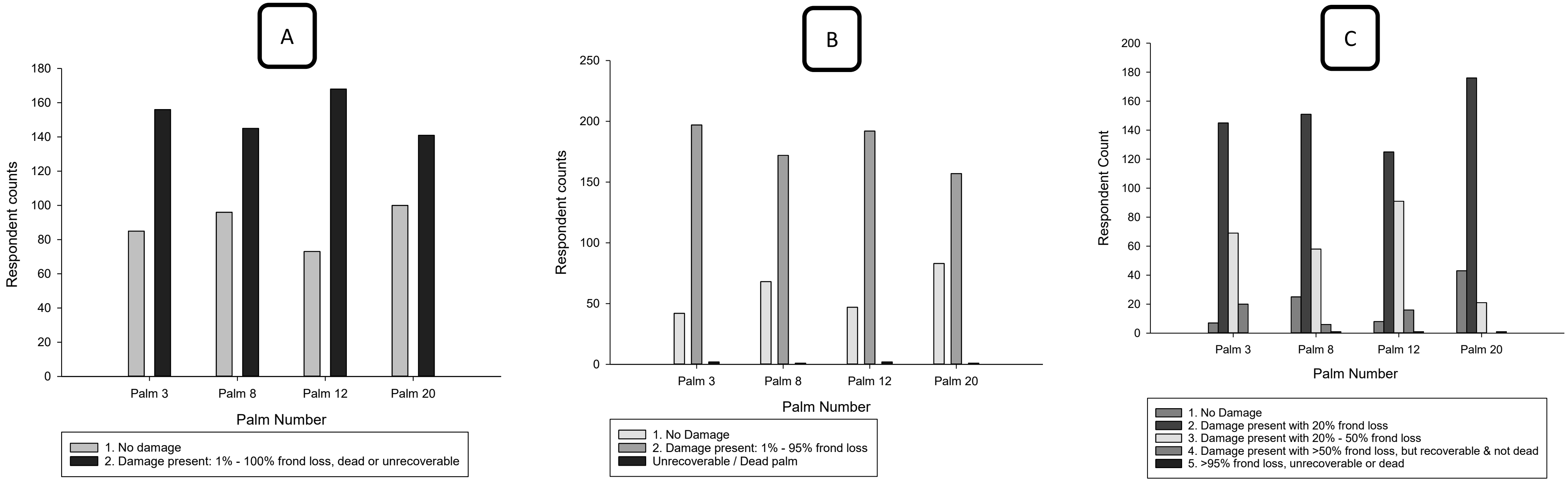


Figure 4-25: Damage grading for palms 3, 8, 12 and 20 A) Binary scale assessment, B) 3-point scale assessment and C) 5-point scale assessment.

Palms 3, 8, 12 and 20 falls in Category 2 in the binary scale and 3-point scale as “Damage present: 1%–100% frond loss, dead or unrecoverable” and “Damage present: 1%–95% frond loss” respectively and in the 5-point scale as Category 3 “Damage present with 20%–50% frond loss". According to the response rates, all palms were graded OK on the binary and 3-point scale (Figure 4-25 A & B), but very poorly in the 5-point scale (Figure 4-25 C). Most respondents graded these Category 3 palms as Category 2 and this was particularly noticeable for Palm 20.

4. Binary: Damage present: 1%–100% frond loss, dead or unrecoverable, 3-point: Damage present: 1%–95% frond loss, 5-point: Damage present with >50% frond loss, but recoverable and not dead.

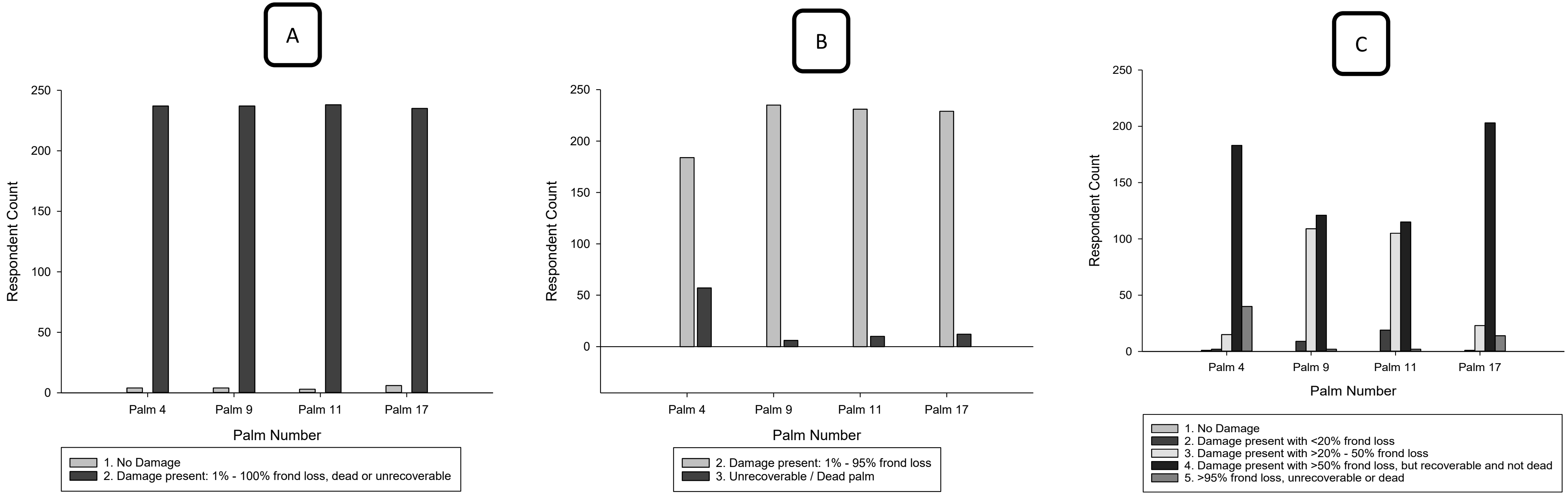


Figure 4-26: Damage grading for palms 4, 9, 11 and 17 A) Binary scale assessment, B) 3-point scale assessment and C) 5-point scale assessment.

Palms 4, 9, 11 and 17 are categorised in the binary and the 3-point scale as Category 2 “Damage present: 1%–100% frond loss, dead or unrecoverable” and “Damage present: 1%–95% frond loss" respectively and Category 4 in the 5-point scale. Grading was accurate for the majority of the respondents for these palms in the binary scale and the 3-point scale (Figure 4-26 A & B). On the 5-point scale, Palm 4 and Palm 17 were accurately graded by the majority of respondents (Figure 4-26 C). However, responses were split for Palm 9 and 11 between Category 3 and Category 4 and is a noticeable change compared with the binary and 3-point responses.

5. Binary: Damage present: 1%–100% frond loss, dead or unrecoverable, 3-point: Unrecoverable / Dead palm, 5-point: >96% frond loss, unrecoverable or dead.

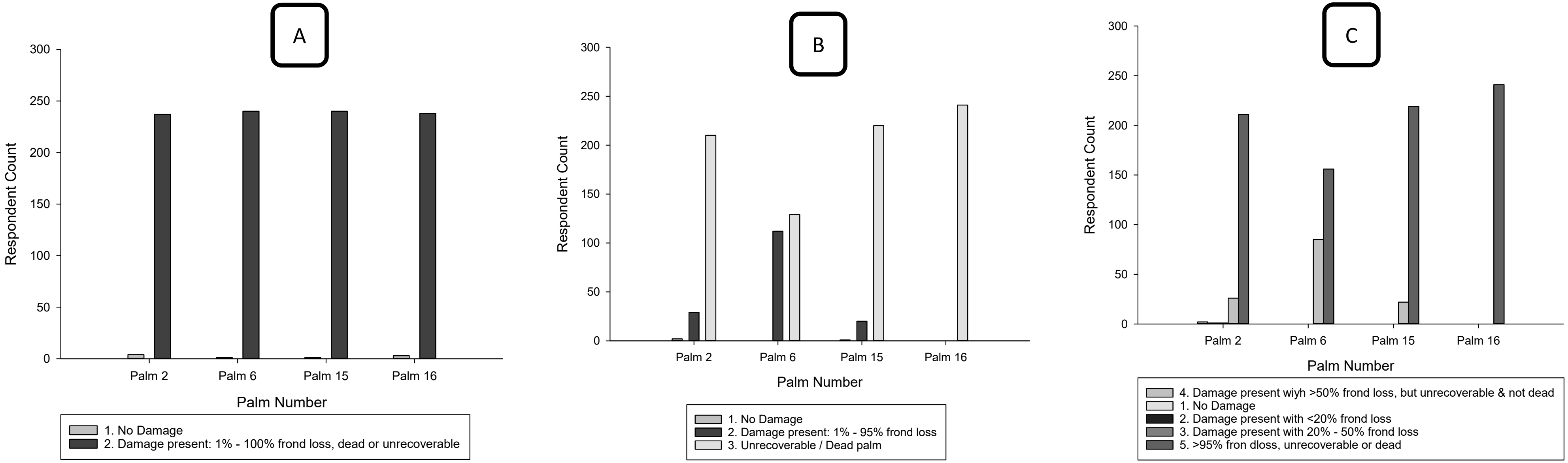


Figure 4-27: Damage grading for palms 2, 6, 15 and 16. A) Binary scale assessment, B) 3-point scale assessment and C) 5-point scale assessment.

Palm 2, 6, 15 and 16 all fall in Category 2, 3 and 5 in the binary, 3-point and 5-point scale respectively. Responses for Palms 2, 15 and 16 were good across the scales including Palm 6 in the binary scale (Figure 4-27 A). However, a split in responses for Palm 6 was observed in the 3-point scale assessment (Figure 4-27 B) and it was also observed that the 3-point scale was the most difficult for this palm.

4.4.3 Influence of Experience on the Damage Scales

For all scales experienced respondents performed better than inexperienced respondents, with a lower proportion of incorrect responses (Figure 4-28). The relative difference between experienced and inexperienced respondents decreased from the binary (approx. 11% increase in incorrect responses) through to the 5-point scale (approx. 7% increase) but was significantly different for all scales (Binary: P=<0.001, 3-point: P= 0.001 and 5-point: P= <0.001).

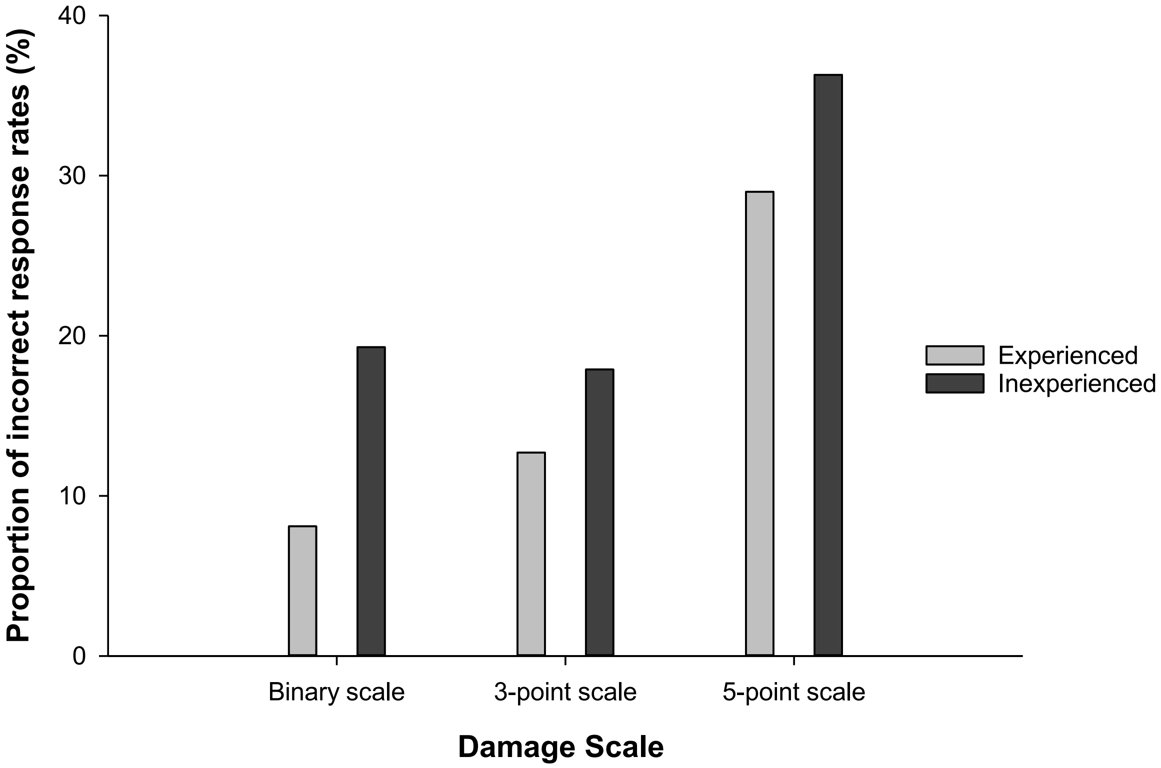


Figure 4-28: Incorrect response rates for Experienced and Inexperienced respondents.

4.4.4 Influence of Professions on the Damage Scales

The results in Figure 4-29 show that incorrect response rates between the professions in each of the scales were not statistically significant except for student vs scientist in the binary scale (P= 0.008) where students had 4.2% more incorrect responses than the scientists. Generally, it was also observed that Scientists performed better in all scales with a relatively lower proportion of incorrect responses compared to others and student.

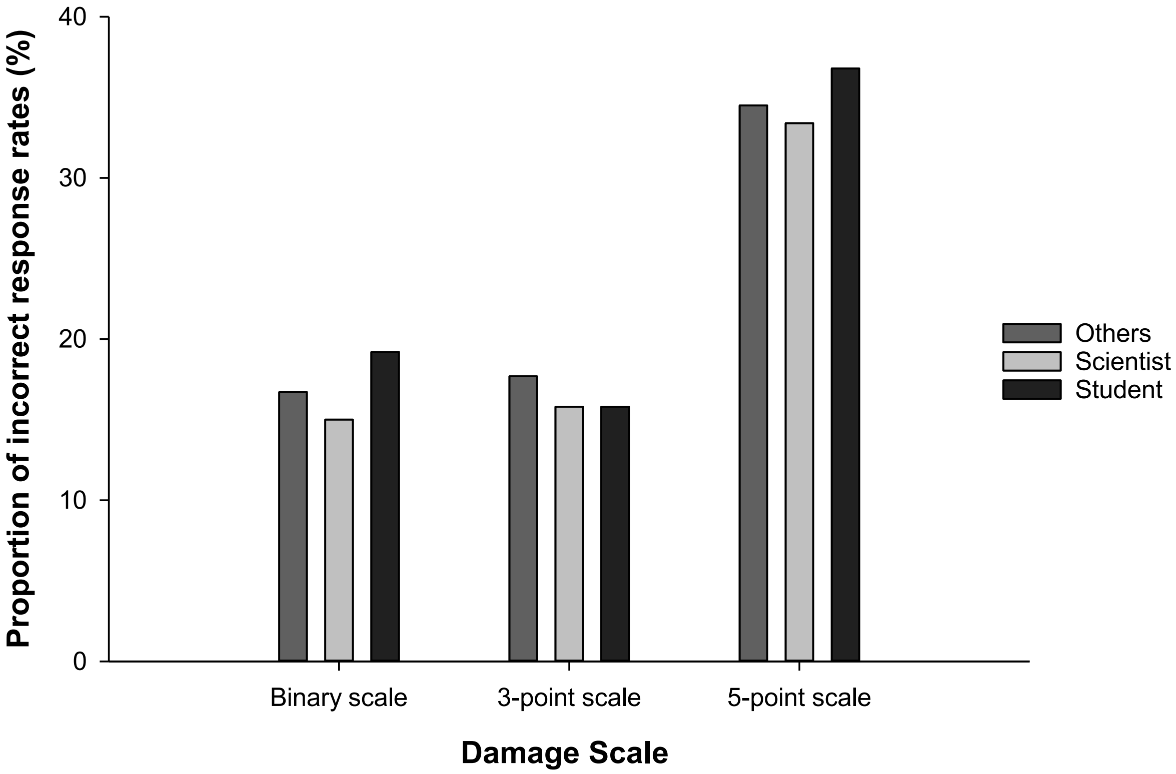


Figure 4-29: Incorrect response rates for the different professions in each scale.

4.4.5 Influence of Place of Residence on the Damage Scales

The results (Figure 4-30) show that the incorrect response rate among respondents living in Asia was significantly lower by 11.3% (P= <0.001) and 10% (P= 0.001) as compared to respondents in ANZ and Others in the binary scale and 7.2% (P= 0.010) and 8.3% (P= 0.010) in the 3-point scale. Similarly, the incorrect response rate of respondents in the Pacific was also significantly lower than those in ANZ and Others by 11.9% (P= <0.001) and 10.6% (P= <0.001) in the binary scale and by 3.1% (P= 0.024) and 4.2% (P= 0.037) in the 3-point scale. Comparisons of incorrect response proportions in the 5-point scale only showed statistical significance for Pacific and others where incorrect response proportions for others was 6.3% (P= 0.014) more than the Pacific.

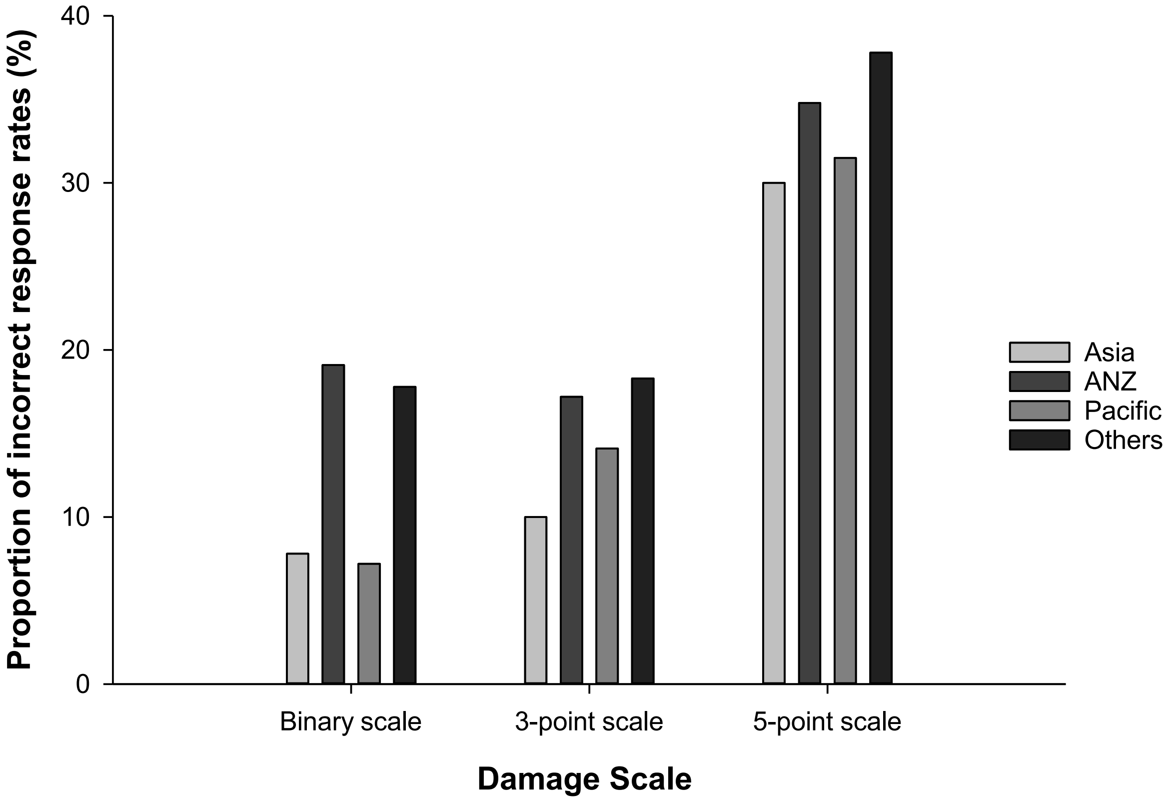


Figure 4-30: Incorrect response rates between the different countries in each scale.

A further test was conducted using the Chi-square test to see if there was any association between the place of residence and experience and to check if the results obtained for these two explanatory variables overlapped with each other. There was a significant association between the respondent's level of experience and their place of residence (χ^2 = 36.54, df = 3, P < 0.001).

Table 4-3: Number of experienced and inexperienced respondents in the different countries.

Place of Residence	Experience	Inexperience
Asia	3	6
ANZ	25	133
Pacific	28	19
Others	10	17

Chapter 5

Discussion and Conclusion

5.1 Introduction

This chapter draws from the results in Chapter 4 and discusses the propositions for the study highlighted in Chapter 2. The propositions involve analysing the existing binary and multi-point scales used in CRB damage assessment studies to test their ability in detecting damage intensity and also the effect assessors have on the accuracy of the scales.

Section 5.2 presents the tests conducted in the photo database assessments to establish the capability of the binary and multi-point scales in detecting damage intensity and changes that occur over time. In section 5.3, the relationship between sample size and effect size are discussed. Section 5.4 determines whether observers affect the accuracy of the binary and multi-point scales. Section 5.5 draws on the key findings and recommendations and section 5.6 delivers the study's contribution, limitations and future research.

5.2 Photo Database

5.2.1 Observations from undamaged palm assessments

The study investigated the performance of the binary, 3-point and 5-point scales in detecting damage intensity and changes that occur over time. I used the assessment for the photo database to establish the performance of the scales with an assumption that grading the same sample population using three different scales would give the same outcome. Two sets of data, undamaged palm counts from all three scales and dead palm counts from the multi-point damage scales in the primary and validation datasets were used to test these assumptions and assess the performance of the scales.

Three comparisons were carried out to test the performance of the scales in their capability to identify undamaged palms. The first comparison was done between the three scales to determine if all scales recorded the same number of undamaged palms in an area. The results showed that, all scales similarly identified undamaged palms and from the comparisons, a 2% difference between the multi-point scales for Solomon Islands was also observed as statistically significant. Interestingly, a much larger difference of 5% between the 3 and 5-point scale for Fiji didn't show the same result statistically and this probed into asking if the p-value was dependent on the sample size. According to Sink & Mvududu (2010), the sample size factor is an important element that not only affects statistical significance but also statistical power. It essential to understand that with increased statistical power in a larger sample size, a trivial effect size can be detected which could be the case for the Solomon Islands in this instance considering Solomon Islands had a sample size >2000 and Fiji with 228 palms. However, due to the lack of literature relating to sample size and effect size in CRB studies that disallow comparative observations and the nuances that are indicated in these results, further analysis on the association of sample size, statistical power and effect size are needed to determine the threshold of effect size in each sample size.

Establishing that the three scales performed similarly in identifying the undamaged palm numbers in the same area, a subsequent assessment to observe the ability of the three scales in identifying undamaged palms between countries was conducted. As mentioned in Chapter 3, the study selected three countries with differing CRB status. Solomon Islands is a country that was severely affected by the new invasive CRB-G biotype and the data that was used for this country depicted the invasion of CRB-G and the extent of this damage 3 years after the incursion. Papua New Guinea on the other hand has both the CRB-S and CRB-G populations present, however, its data were derived from an area where only a controlled CRB-S population existed. Similar to the data from PNG, Fiji only has a CRB-S population that is being managed by OrNV. These distinctions between the countries put into perspective how the results were intended with both PNG and Fiji having similar standing on their status of CRB and SI where infection rates were higher and without the biological control. From the results, the three scales were able to identify the undamaged palms between the three countries consistently and also reflected the reliability and accuracy of the scales in identifying and distinguishing the differences in CRB status between the three countries.

The third assessment investigated the ability of the scales in identifying changes in the proportions of undamaged palms over time. Comparative results were drawn from the proportions of undamaged palms from two separate comparisons. Firstly, between Henderson and GPPOL from two time periods, January and November using the primary dataset and secondly between Henderson and GPPOL's January and November 2018 data against the Solomon Islands in 2020 from the validation dataset. The results from these comparisons showed that both the binary and 3-point scales performed similarly while the 5-point scale displayed different results. Significant results could only be pulled out from the comparison between Henderson in January 2018 and Solomon Islands in 2020 in the binary and 3-point scales. The results showed that a change was only detectable when the differences in proportions were at a minimum of 5% and between a period equivalent to 2 years and more. In contrast, the comparisons involving 10 and 15-month timeframes were not suitable for detecting or monitoring changes. The findings further showed an increase of undamaged palm proportions from 2018 into 2020 with the largest differences detected from the comparisons between Henderson and GPPOL in January 2018 against the Solomon Islands in 2020.

It is apparent that the 2-year timeframe stands out as an important factor in the monitoring perspective, considering the results evidently shows changes are detectable within this timeframe. It is however difficult to draw any comparisons from the documented CRB studies due to the lack in replicable and quantitative data in the methods used (Bedford, 1980). However, it can be reasoned that the detectable timeframe lays within the period of the new frond growth which is described in the work of Young (1975) and Gressitt (1953).

5.2.2 Observations from dead palm assessments

Similar to the observations of the undamaged palm numbers, dead palm proportions were used to test if the 3-point and 5-point scales produced consistent results in three different comparisons. In comparison 1 (C1), the scales were compared against each other while in the second comparison (C2) performance of the multi-point scales were compared separately between countries. Results from these two comparisons and the third comparison (C3) where dead palm proportions in each scale were compared against a time difference, showed that the multi-point scales produced similar results throughout. C2 again highlighted the ability of the scales in identifying the variations between the different situations in Solomon Islands, PNG and Fiji. The comparison reflected the low number of standing dead palms in PNG and Fiji as compared to the Solomon Islands where dead palm proportions are distinctly higher and this finding is consistent with studies by Paudel et al. (2021). From the third comparison (C3), results indicated that a 10 month monitoring period was not enough to detect any significant differences as compared to a prolonged 1–2 years monitoring time where a minimum reduction of 9.6% and 8.6% in the 3 and 5-point scales are detectable from sample sizes between 104–120 and 120–190 palms respectively. The results also showed that the largest difference in proportions of dead palms was recorded in November.

The ability of the scales in detecting changes and monitoring them over time is evident and can be seen from the results of both the undamaged and dead palms in the Solomon Islands. From the results, there was an increase in both undamaged and dead palm numbers from January to November 2018 in Henderson and GPPOL, but the rate of increase was greater for the proportion of dead palms. This could be due to the progressive damaging levels of CRB after the incursion period. These increased levels of dead palm numbers have been reported elsewhere (Vaqalo et al. 2020; Tsatsia et al. 2018). A year after that observation, a huge drop in dead palm numbers was detected in the two localities. This could be attributed to the ongoing sanitation programme implemented in the Solomon Islands. In the 2-year monitoring timeframe between Henderson and GPPOL in January 2018 versus the Solomon Islands in 2020, the proportions of undamaged palms had eventually increased while a further drop in the proportion of dead palms was recorded. These findings were adequate to pick up trends and to indicate whether management efforts were improving palm health, where these were being implemented.

5.3 Effect of Sample Size

The results from the photo database assessments indicated that an association between sample size and the effect size was present. Effect size is the degree to which the phenomenon is present (Cohen, 1988). The simulated random sample sizes consisting of 100, 90, 75 and 50 undamaged palms showed that only a 6% change in the proportion of undamaged palms from a sample of 100 palms was detectable in the binary and 3-point scale over a 2-year timespan. Although a 6% change was also observed from 50 undamaged palms, the results of these sample population was not statistically significant indicating that the change is only significant in a sample population of 100 palms. Further analysis needs to be conducted to investigate the relationship between minimum detectable effect size and sample size for each damage scale.

5.4 Online Survey

An online survey was administered to examine whether assessors affected the accuracy of the damage scales used in CRB studies and investigated some of the sources that may potentially have an impact on the way scales are used.

Primarily, we wanted to find out in general which of the three scales was the simplest to use among the assessors and results from the overall scale assessment identified the binary scale as the simplest, reflecting the findings of Young (1975). This was indicated from the higher accuracy rate observed in the binary scale than the 3 and 5-point scales where the accuracy for grading palms in the survey decreased as the grading scale increased. The results also showed that the differences in the correct and incorrect answers between the three scales when assessed as a whole were large and statistically significant against each other.

The results gathered from individual responses within each scale determined further, a higher accuracy rate in the binary scale than in the 3 and 5-point scales. However, correct response rates from the 3-point scale were very similar to the binary scale such that variations between them were not statistically significant unlike the 5-point scale that differed significantly from both the binary and 3-point scale. According to the results, we can argue that the 5-point scale has a very low accuracy rate despite its ability to collect specific data reported in past studies (Ero, 2015; Jackson & Sailo, 2017; Vaqalo et al., 2017). This reflects the fact that the 5-point scale can be subjective, and with subjective content, studies have found that respondents tend to overestimate the amount of damage (Godoa et al. 2006) or rely on experience and training (Innes, 1988) which are major sources of inconsistencies and variation among assessors.

It was further observed that assessors performed better in identifying the palms at low and high levels of severity as compared to the mid-ranged levels. This means that the "No Damage" category in all scales and the "Dead and Non-recoverable" category in the multi-point scales were more accurately graded than the palms belonging to the mid-ranged categories especially 2 and 3 in the 5-point scale. The lack of literature for scale accuracy in CRB studies makes comparative reasoning difficult, however, results from the survey are consistent with similar plant disease and damage assessments carried out by Koch & Hau (1980) and Hau et al (1989) as cited in Bock et al. (2010).

5.4.1 Assessor influence

From the results of the survey especially in the 5-point scale that indicated a low accuracy in damage grading, the study investigated whether the characteristics of the assessors influenced these outputs. Experience, profession and place of residence of each respondent were tested against the incorrect responses in each scale to determine if they had any impact of these factors on the scales.

Observations for experience influence

According to the results, experienced respondents performed better than inexperienced respondents, with a lower proportion of incorrect responses than expected. Although there are no studies done specifically for CRB damage scales, that prove the influence of experience on scale accuracy or more so prove that experience improves the accuracy of damage scales, the findings are consistent with comparative studies in the field of plant diseases (Bock et al., 2010; Newton & Hackett, 1994; Sherwood, Berg, Hoover, & Zeiders, 1983). These studies found that assessors scoring of damage severity levels varied between experienced and inexperienced assessors and that experienced raters tended to do better at estimating diseases. Despite experienced respondents performing better than inexperienced respondents in general, their accuracy still reduced with the increase in damage scales. The results from the experienced population showed they performed better in the binary and this accuracy dropped as they progressed into the 3 and 5-point scales. Relatively, the incorrect responses from experienced and inexperienced respondents increased from binary to the 5-point damage scale. While Innes (1988) argues that experience and training improve accuracy, the findings from the survey showed that the reliability of this factor is correct generally but is not equal between the scales.

Observations for profession influence

The influence of profession was also assessed to determine if a profession in the science field indirectly affected the way assessors used the scales to assess CRB damage, but comparisons were done against students and "others" which consisted of the non-science fields showed no associations between professions and the number of incorrect responses in the three scales.

Observations for place of residence influence

The study wanted to determine whether the indirect experience of CRB through the place of residence influenced the performance of assessors in the scales. Results indicated that an association between response rates of assessors and the place where they reside was present. The argument is that a person is likely to know of CRB or its damage symptoms if they reside in a place where CRB is present. It was assumed that this familiarization affected the performance of the respondents. Results showed that respondents living in Asia and the Pacific where coconuts and CRB are present generally performed better with lower proportions of incorrect answers than respondents living in Australia/NZ and other countries like the USA, South Africa and France.

Moreover, an exploration of survey data suggested the likelihood of an accidental association between the place of residence and experience with coconut and coconut pests. With this assumption a chi-square test was conducted which confirmed the association of the two explanatory variables thus, it was not possible to separate the relative impact of these two factors. With these latter finding and the lack of proof to disassociate the place of residence from experience, the influence of the place of residence in the accuracy of the scales was inconclusive and requires further testing to determine its effect.

5.5 Key findings and future work

The main objectives of this study were (a) to establish the capability of binary and multi-point scales in detecting damage intensity and changes that occur over time, and (b), to determine whether observers affect the accuracy of the binary and multi-point scales. This study was particularly relevant in that effective damage assessment and monitoring tools were ill studied so understanding the factors that affected them was vital as addressing the effects can in turn contribute immensely to the successful management of CRB. The study sought to answer two research questions:

1. Which scales can detect damage intensity and changes that occur over time?
2. Do the observers affect the accuracy of the data collected using the binary and multi-point scales?

To address these research questions the study drew on existing CRB literature that used damage assessment scales to ascertain the performance of the scales and an experimental survey to identify the determinants that influence an assessor's accuracy in the scales. At the start of the study, it was established that CRB work had lacked the literature that understood the effectiveness of the damage assessment and monitoring tools. The study noted that damage scales were extensively used throughout CRB studies but within a limited spectrum and without any standardised approach. Also, no evidence showed the accuracy of these existing scales.

The main findings are chapter-specific and were presented and discussed in Chapters 4 and 5. The first research question and its objective were investigated through the damage assessment grading and the comparisons between three different scenarios. Findings from the damage grading and tests found that all scales could detect damage and at different levels of intensity. They also produced consistent results in their identification of undamaged palms and the multi-point scales performed similarly in identifying dead palms. The results of the comparison between the scales identified a correlation between sample size and effect size, where a high population size (>2000) could detect a small and significant change (2%) but inversely, a low population (228) with a larger change (5%) was not significant. These findings probe inquiry into investigating further the correlation between the sample size and effect size in future work.

The question to the scales' ability in monitoring changes over time was satisfied with the comparison results between Henderson and GPPOL in January and November in 2018 and also those between the Solomon Islands in 2020. These results found that recovery and management efforts such as sanitation are detectable in a 2-year timeframe. However, it is only detectable if the change is within a minimum of 5% in a sample size that is >100. The findings from the dead palm proportions tests also found that 10-month monitoring intervals are not sufficient and if any change is anticipated within 1 year, a larger sample size (120-190) with an effect size at a minimum of 10.5% is feasible. Two other supplementary findings were learnt from these results, including the scale's ability to reflect a country's CRB status which was uncovered from the comparisons done for the scales between countries. Also discovered through the process of comparing timeframes was the visibility of a trend in the Solomon Islands where the impacts of sanitation and beetle invasion can be traced.

The second research question enquired on the influence of assessors that affected the accuracy of the scales. This research question and the objective that was aligned with it were satisfied through an online survey that studied the responses of 241 respondents with and without the knowledge of CRB. The results from the online survey showed that both the binary and 3-point scales had a higher accuracy rate than the 5-point scale across all respondents. Damage intensity between the scales was assessed more accurately in the lowest and the highest severity levels while the mid-level ranges were challenging and more difficult for the respondents to score. Results from the survey also found that experience improved the accuracy in the scales, meaning, people with direct exposure to work relating to coconut and coconut pests were seen to perform better than respondents without any experience. The influence of place of residence showed a positive effect on the accuracy of the scales, however, an association between place of residence and experience, showed that the results collated for the place of residence were not independent of those of experience. These findings propose an inquiry into investigating the effect of place of residence on the accuracy of the scales independent from experience.

5.6 Study's contribution and limitations

This study contributed to the literature by documenting the factors that affect the performance of the binary, 3-point and 5-point scales in identifying damage intensity and the changes that occur over time. The research also generated data that uncovered factors and characteristics of assessors that influence their damage scoring process specifically, in the damage scales used in CRB studies. Findings from the study assisted in identifying aspects of the damage assessment method that need to be rectified.

One of the key limitations of this study was the lack of literature pertaining to the effectiveness of the damage scales used in CRB studies. The absence of relative studies made it difficult for comparative reasoning. Another factor was the impacts incurred through the Covid-19 pandemic, which restricted certain study elements that affected the research process.

Going forward, more studies into reinforcing robust and effective damage assessment and monitoring tools are essential. The outcomes of these future studies will provide comparative results that will assist to improve and strengthen existing methods. All in all, these efforts will contribute to the effective and successful management of CRB in the Pacific and the wider regions.

References

Bailey, P., O'Sullivant, D., & Perry, C. (1977). Effect of artificial defoliation on coconut yields in Papua New Guinea. *Papua New Guinea Agricultural Journal, 28*(2,3,4), 39-45.

Batugal, P. A. (1999). The role of international cooperation in the development of biotechnology in coconut. In C. V. Oropeza, J. L. Ashburner, G. R. Cardena, R. Santamaria, J. M (Ed.), Current Advances in Coconut Biotechnology (Vol. 35, pp. 19-30). Dordrecht, Netherlands: Springer, Dordrecht. doi:https://doi.org/10.1007/978-94-015-9283-3_2

Bedford, G. O. (1976). Observations on the Biology and Ecology of *Oryctes rhinoceros* and *Scapanes australis* (Coleoptera: Scarabaeidae: Dynastinae) *Australian Journal of Entomology, 15*(3), 241-251.

Bedford, G. O. (1980). Biology, ecology, and control of palm rhinoceros beetles. *Annual Review of Entomology, 25*, 309-339.

Bedford, G. O. (2013a). Biology and Management of Palm Dynastid Beetles: Recent advances. *The Annual Review of Entomology, 58*, 353-372. doi:10.1146/annurev-ento-120710-100547

Bedford, G. O. (2013b). Long-term reduction in damage by rhinoceros beetle *Oryctes rhinoceros* (L.) (Coleoptera: Scarabaeidae: Dynastinae) to coconut palms at *Oryctes Nudivirus* release sites on Viti Levu, Fiji. *African Journal of Agricultural Research, 8*(49), 6422-6425. doi:10.5897

Bedford, G. O. (2014). Advances in the control of rhinoceros beetle, *Oryctes rhinoceros* in oil palm. *Journal of Oil Palm Research, 26*(3), 183-194.

Bock, C. H., Poole, G. H., Parker, P. E., & Gottwald, T. R. (2010). *Plant Disease Severity Estimated Visually, by Digital Photography and Image Analysis, and by Hyperspectral Imaging.* Vol. 29. (pp. 59-107). Retrieved from https://www.researchgate.net/publication/46247553_Plant_Disease_Severity_Estimated_Visually_by_Digital_Photography_and_Image_Analysis_and_by_Hyperspectral_Imaging/link/00b49538e2ca4773d9000000/download doi:10.1080/07352681003617285

Catley, A. (1969). The coconut rhinoceros beetle *Oryctes rhinoceros* (L) [Coleoptera: Scarabaeidae: Dynastinae]. *PANS, 15*, 18-30.

Chan, E., & Elevitch, C. R. (2006). *Cocos nucifera* (coconut) Retrieved 25/11/2020 http://www.agroforestry.net/images/pdfs/Cocos-coconut.pdf

Cohen, J. (1988). Statistical power analysis for behavioural sciences.

Cumber, R. A. (1957). Ecological studies of the rhinoceros beetle *Oryctes rhinoceros* (L,.) in Western Samoa. *South Pacific Commission Technical Paper* (107).

Davis, A. T. (1971). Why Fibonacci sequence for palm leaf spirals? Indian Statistical Institute, Calcutta, India.

Deutscher, S., Dillon, M., McKinnon, C., Mansfield, S., Staines, T., & L., L. (2003). Giving a good beating. *The Australian Cotton grower, 24*(3), 24-27.

Ero, M. (2015). Report on the Detection of the "Guam Biotype" of *Oryctes rhinoceros* (Coleoptera: Scarabaeidae) in Port Moresby, National Capital District, (NCD), Papua New Guinea (PNG). Retrieved from https://www.cabdirect.org

Etebari, K., Filipovic, I., Rasic, G., Devine, G., J., Tsatsia, H., & Furlong, M., J. (2020). Complete genome sequence of *Oryctes rhinoceros nudivirus* isolated from the coconut rhinoceros beetle in Solomon Islands *Elsevier Science Publishers, 278*. doi:https://doi-org.ezproxy.lincoln.ac.nz/10.1016/j.virusres.2020.197864

Etebari, K., Hereward, J., Sailo, A., Ahoafi, E. M., Tautua, R., Tsatsia, H., Furlong, M., J. (2020). Genetic structure of the Coconut Rhinoceros Beetle (*Oryctes rhinoceros*) population and the incidence of its biocontrol agent (*Oryctes nudivirus*) in the South Pacific Islands. doi:DOI: 10.1101/2020.07.30.229872

Foale, M. (2003). *The coconut odyssey: the bounteous possibilities of the tree of life.* Vol. 101. *ACIAR Monograph* (pp. 132p).

Gitau, W. C., Gurr, M. G., Dewhurts, F. C., Fletcher, J. M., & Mitchell, A. (2009). Insect pests and insect-vectored diseases of palms. *Australian Journal of Entomology, 48*, 328-342. doi:10.1111/j.1440-6055.2009.00724.x

Godoy, C. V., Koga, L. J., & Canteri, M. G. (2006). Diagrammatic scale for assessment of soybean rust severity. *Fitopatologia Brasillerira, 31*(1), 63-68.

Gressitt, J. L. (1953). The coconut rhinoceros beetle (*Oryctes rhinoceros*) with particular reference to the Palau Islands. *Bernice P. Bishop Museum, Bulletin 212*.

Hinckley, A. D. (1973). Ecology of the coconut rhinoceros beetle, *Oryctes rhinoceros* (L.) (Coleoptera: Dynastidae). *Biotropica, 5*(2), 111-116.

Jackson, T., Mansfield, S., & Atumurirava, F. (2020). Coconut rhinoceros beetle (*Oryctes rhinoceros*): A manual for control and management of the pest in Pacific Island countries and territories. Retrieved from348756353_Coconut_rhinoceros_beetle_Oryctes_rhinoceros_A_manual_for_control_and_management_of_the_pest_in_Pacific_Island_countries_and_territories

Jackson, T., Marshall, S., Mansfield, S., & Atumurirava, F. (2021). *Coconut rhinoceros beetle (Oryctes rhinioceros): A manual for control and management of the pest in the Pacific Island countries and territories.* Suva, Fiji: Pacific Community (SPC).

Jackson, T., Marshall, S., Mansfield, S., & F., A. (2020). Coconut rhinoceros beetle (*Oryctes rhinoceros*): A manual for control and management of the pest in the Pacific Island countries and territorie. Pacific Community (SPC).

Jackson, T., & Marshall, S. D. G. (2017). The Role of *Oryctes nudivirus* in management of the coconut rhinoceros beetle, *Oryctes rhinoceros*. *Japanese Society for Insect Pathology*.

Jackson, T., & Sailo, A. (2017). *Rhinoceros beetle rapid damage assessment- Taveuni*.

Kokonas Indastri Koporesen. (2017). Coconut industry in the PNG economy. [Press release]. Retrieved from http://www.kik.com.pg/coconut-industry-in-png-economy/

Mankin, R. W., & Moore, A. (2010). Acoustic detection of *Oryctes rhinoceros* (Coleoptera: Scarabaeidae: Dynastinae) and *Nasutitermes luzonicus* (Isoptera: Termitidae) in Palm trees in urban Guam. *Journal of Economic Entomology, 103*(4), 1135-1143. doi:10.1603/EC09214

Marshall, S., Moore, A., Vaqalo, M., Noble, A., & Jackson, T. A. (2017). A New Haplotype of the Coconut Rhinoceros Beetle, *Oryctes rhinoceros*, has escaped biological control by *Oryctes rhiniceros* nudivirus and is Invading Pacific Islands

Journal of Invertebrate Pathology, 149, 127-134. doi:https://doi-org.ezproxy.lincoln.ac.nz/10.1016/j.jip.2017.07.006

Marshall, S. D. G., Moore, A., & Vaqalo, M. (2016). A New Coconut Rhinoceros Beetle Biotype Threatens Coconut and Oil Palms in Southeast Asia and the Pacific.

McGregor, A., & Sheehy, M. (2017). *An overview of the market for Pacific Island coconut products and the ability of industries to respond.* Suva, Fiji: Pacific Community (SPC).

McGregor, A., & Sheehy, M. (2017). *An overview of the market for Pacific Island coconut products and the ability of industries to respond.* Retrieved from Suva, Fiji:

Moore, A. (2018). The Coconut Rhinoceros Beetle Problem on Guam: Past, Present and Future (Publication no. http://doi.org/10.5281/zenodo.1185371). https://zenodo.org/record/1185371#.Xoxg7G5uJjo

Newton, A. C., & Hackett, C. A. (1994). Subjective components of mildew assessment on spring barley. *European Journal of Plant Pathology, 100*, 395-412. doi:10.1007/BF01874807

Pacific Community (SPC). (2017). A new biotype of Coconut Rhinoceros Beetle discovered in the Pacific [Press release]. Retrieved from https://www.spc.int/sites/default/files/wordpresscontent/wp-content/uploads/2017/08/Pest-Alert-52-Coconut-Rhino-Beetle2016-spc-lrd.pdf

Paudel, S., Marshall, S., Tsatsia, F., Fanai, C., Kolubalona, M., Mansfield, S., Jackson, T. (2021). Monitoring an invasive coconut rhinoceros beetle population using pheromone traps in Honiara, Solomon Islands. New Zealand Plant Protection, 74(1): 37-41. DOI:10.30843/nzpp.2021.74.11742

Redfern, D. B., & Boswell, R. C. (2004). Assessment of crown condition in forest trees: comparison of methods, sources of variation and observer bias. *Forest Ecology and Management, 188*, 149-160. doi:10.1016/j.foreco.2003.07.011

Santos, G. A., Batugal, P. A., Othman, A., Baudouin, L., & Labouisse, J. P. (Eds.). (1996). *Manual on Standardized Research Techniques in Coconut Breeding*.

Sherwood, R. T., Berg, C. C., Hoover, M. R., & Zeiders, K. E. (1983). Illusions in Visual Assessment of Stagonospora Leaf Spot of Orchardgrass. *Phytopathology, 73*(2), 173-177.

Sink, C. A., & Mvududu, N. H. (2010). Statistical Power, Sampling, and Effect Sizes: Three Keys to Research Relevancy. *Sage Publications, 1*(2), 1-8. doi:10.1177/2150137810373613

Smith, A. H., Pinkard, E. A., Stone, C., Battaglia, M., & Mohammed, C. L. (2005). Precision and accuracy of pest and pathogens damage assessment in young eucalypt plantations *Environmental Monitoring and Assessment, 111*, 243-256. doi:10.1007/s10661-005-8222-5

Tsatsia, F., Wratten, H., Gharuka, M., Fanai, C., Wate, D., Tsatsia, H., Mcfarlane, B. (2018). The status of Coconut Rhinoceros Beetle, *Oryctes rhinoceros* (L) Scarabaeidae: Dynastinae, in Solomon Islands. Ministry of Agriculture and Livestock, Honiara, Solomon Islands. Retrieved from Status-of-the-coconut-rhinoceros-beetle.pdf (devpolicy.org)

United States Department of Agriculture (USDA). 2015. New Pest Response Guidelines: *Oryctes rhinoceros* (L.) Coleoptera: Scarabaeidae, Coconut Rhinoceros Beetle, New Pest Response Guidelines. Government Printing Office, Washington, D.C.

Vaqalo, M., Timote, V., Baiculacula, S., Suda, G., & Kwainarara, F. (2017). The Coconut Rhinoceros Beetle in Solomon Islands: A Rapid Damage Assessment of Coconut Palms on Guadalacanal.

Young, E. C. (1975). A study of rhinoceros beetle damage in coconut palms. South Pacific Commission, Noumea, New Caledonia: South Pacific Commision.

Young, E. C. (1986). The Rhinoceros Beetle Project: History and Review of the Research Programme. *Science Direct, 15*(2-3), 149-166. doi:https://doi-org.ezproxy.lincoln.ac.nz/10.1016/0167-8809(86)90088-5

Zelazny, B., & Alfiler, A. R. (1987). Ecological methods for adult populations of *Oryctes rhinoceros* (Coleoptera, Scarabaeidae). *Ecological Entomology, 12*, 227-238.

Appendix A

Online Survey Questionnaire

Comparison of methods used to assess coconut rhinoceros beetle (*Oryctes rhinoceros*) damage.

PARTICIPATION INFORMATION STATEMENT FOR ONLINE SURVEY

Introduction and Invitation I invite you to participate in a project entitled "Comparison of methods used to assess coconut rhinoceros beetle (*Oryctes rhinoceros*) damage". Your participation will be through an online survey which will take around 15–20 minutes to complete.

What is the aim of the project? Coconut is an essential crop in Pacific societies. It is an important small-holder crop and contributes to food security, nutrition, employment and income generation. One insect pest that affects coconut production is the scarab beetle *Oryctes rhinoceros* commonly known as coconut rhinoceros beetle (CRB). CRB is a significant pest of coconut palms that reduces coconut productivity and may cause death of the palm. This pest poses a serious threat to the industry. Proper management approaches are needed to protect the coconut palms from CRB. This study aims to develop a unified method of damage assessment for CRB. The study will use three different damage assessment scales: binary, a 3-point, and a 5-point damage scale, to assess CRB damage on coconut palms in both Papua New Guinea and the Solomon Islands. I will test the consistency of these three different damage assessment scales between different observers (survey participants). The survey responses will contribute to developing damage assessment protocols for CRB on coconut palms. This will support ongoing efforts to manage invasive CRB populations in the Pacific. This survey is conducted by Balanama Asigau (student) and will form the basis for the degree of Master in Science at Lincoln University, New Zealand, under the supervision of Dr. Sarah Mansfield (Adjunct Senior Lecturer) and Mike Bowie (Senior Tutor). The study is funded by the Bio-Protection Research Centre and the New Zealand Ministry of Foreign Affairs and Trade.

How were you selected? You were selected because of your engagement with an agriculture or quarantine organization, research institution or university or you have some experience with palm pests and/or assessing palm health.

What will you be asked to do? You will be asked to score a set of pictures using three different damage assessment scales. The questionnaire is anonymous, and you will not be identified as a respondent without your consent. You may at any time before submitting the survey withdraw your participation, including withdrawal of any information you have provided. If you complete the questionnaire and submit, however, it will be understood that you have consented to participate in the project and to the publication of the results of the project with the understanding that anonymity will be preserved.

How will my data be used? The survey responses will be used to compare the consistency of these three different damage assessment scales between different observers (survey participants). This comparison will contribute to developing damage assessment protocols for CRB on coconut palms. These data will be accessible to the student and the supervisory team. Anonymity will be upheld with no names required in the questionnaire and the survey data will be aggregated for analysis and presentation. The results of the survey will be published as part of the research thesis and will contribute to ongoing efforts to manage CRB.

CONSENT FORM

Name of Project: "Comparison of methods used to assess coconut rhinoceros beetle (*Oryctes rhinoceros*) damage". 1. I have read and understood the description of the project above. 2. I have been given sufficient time to consider whether or not to participate in the survey. 3. I understand that I may withdraw from the survey, including withdrawal of any information I have provided, at any time before the "SUBMIT" button is selected. You may at any time withdraw your participation, including withdrawal of information you have provided. If you submit the questionnaire, however, it will be understood that you have consented to participate in the project and consent to publication of the end results of the project with the understanding that anonymity will be preserved.

○ I consent to participate in the survey and to the publication of the results, with the proviso that anonymity is preserved.

INTRODUCTION

Hello, thank you for participating in my survey. The survey is in three different sections and should take around 15-20 minutes to complete. In each section you will be asked to assess photos of coconut palms for CRB damage using the Grading Scale provided.

Binary grading scale

Section 1: Using the BINARY grading scale provided

Grade and Scale Description	
1	**2**
	
No CRB damage symptoms evident	CRB damage symptoms present

Choose:
1. If there is **no damage** on the coconut palm OR
2. If damage to the coconut palm is evident: 1%–100% frond loss, dead or unrecoverable.

Palm 1

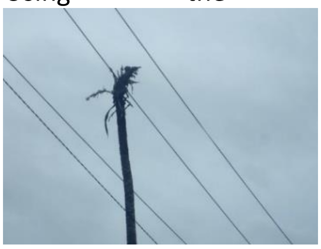
Using the BINARY grading scale, assess Palm 1.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 2

Using the BINARY grading scale, assess Palm 2.



Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100%

Palm 3
Using the BINARY grading scale, assess Palm 3.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable.

Palm 4
Using the BINARY grading scale, assess Palm 4.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 5
Using the BINARY grading scale, assess Palm 5.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 6

Using the BINARY grading scale, assess Palm 6.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 7

Using the BINARY grading scale, assess Palm 7.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 8

Using the BINARY grading scale, assess Palm 8.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss

Palm 9
Using the BINARY grading scale, assess Palm 9.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 10
Using the BINARY grading scale, assess Palm 10.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 11
Using the BINARY grading scale, assess Palm 11.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 12

Using the BINARY grading scale, assess Palm 12.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 13

Using the BINARY grading scale, assess Palm 13.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 14

Using the BINARY grading scale, assess Palm 14.

Choose:

- ◯ 1. No damage
- ◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 15
Using the BINARY grading scale, assess Palm 15.

Choose:

◯ 1. No damage

◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 16
Using the BINARY grading scale, assess Palm 16.

Choose:

◯ 1. No damage

◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 17
Using the BINARY grading scale, assess Palm 17.

Choose:

◯ 1. No damage

◯ 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 18
Using the BINARY grading scale, assess Palm 18.

Choose:

- 1. No damage
- 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 19
Using the BINARY grading scale, assess Palm 19.

Choose:

- 1. No damage
- 2. Damage present: 1%–100% frond loss, dead or unrecoverable

Palm 20
Using the BINARY grading scale, assess Palm 20.

Choose:

- 1. No damage
- 2. Damage present: 1%–100% frond loss, dead or unrecoverable

3-point grading scale

Section 2: Using the 3-POINT grading scale provided

Grade and Scale Description		
1	2	3
 No CRB damage symptoms evident.	 Multiple fronds affected. Notching and breakage.	 Non-recoverable. Palm dead or with growing point destroyed.

Choose:
1. If there is **no damage** on the coconut palm OR
2. If the coconut palm shows 1%–95% frond loss OR
3. If palm is dead, non-recoverable and growing point destroyed

---

Palm 1

Using the 3-POINT grading scale, assess Palm 1.

Choose:

◯ 1. No Damage

◯ 2. Damage present: 1%–95% frond loss

◯ 3. Unrecoverable / Dead palm

Palm 2

Using the 3-POINT grading scale, assess Palm 2.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 3

Using the 3-POINT grading scale, assess Palm 3.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 4
Using the 3-POINT grading scale, assess Palm 4.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 5
Using the 3-POINT grading scale, assess Palm 5.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 6

Using the 3-POINT grading scale, assess Palm 6.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 7

Using the 3-POINT grading scale, assess Palm 7.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 8

Using the 3-POINT grading scale, assess Palm 8.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 9

Using the 3-POINT grading scale, assess Palm 9.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 10

Using the 3-POINT grading scale, assess Palm 10.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 11

Using the 3-POINT grading scale, assess Palm 11.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 12
Using the 3-POINT grading scale, assess Palm 12.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 13
Using the 3-POINT grading scale, assess Palm 13.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 14
Using the 3-POINT grading scale, assess Palm 14.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 15
Using the 3-POINT grading scale, assess Palm 15.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 16
Using the 3-POINT grading scale, assess Palm 16.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 17
Using the 3-POINT grading scale, assess Palm 17.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 18

Using the 3-POINT grading scale, assess Palm 18.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 19

Using the 3-POINT grading scale, assess Palm 19.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present: 1%–95% frond loss
- ◯ 3. Unrecoverable / Dead palm

Palm 20

Using the 3-POINT grading scale, assess Palm 20.

Choose:

- 1. No Damage
- 2. Damage present: 1%–95% frond loss
- 3. Unrecoverable / Dead palm

5-point grading scale

Section 3: Using the 5-POINT grading scale provided

Grade and Scale Description				
1	**2**	**3**	**4**	**5**
 No CRB damage symptom evident	 **Light**-light damage. Notching or tip damage. <20% frond loss.	 **Medium**-Multiple fronds affected. Notching and breakage. 20%-50% frond loss.	 **High**- Multiple fronds affected. Notching and breakage. >50% frond loss, but recoverable and not dead.	 Non-recoverable. Palm dead or with the growing point destroyed.

Choose:

1. If there is no damage on the coconut palm OR
2. If the coconut palm has <20% frond loss OR
3. If the coconut palm has 20-50% frond loss OR
4. If the coconut palm has >50% frond loss OR
5. If palm has >95 frond loss, is dead, non-recoverable and growing point destroyed

Palm 1

Using the 5-POINT grading scale, assess Palm 1.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 2

Using the 5-POINT grading scale assess Palm 2

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 3
Using the 5-POINT grading scale assess Palm 3.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with 20% frond loss
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with 50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 4
Using the 5-POINT grading scale assess Palm 4.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with >20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 5

Using the 5-POINT grading scale assess Palm 5.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 6

Using the 5-POINT grading scale assess Palm 6.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 7

Using the 5-POINT grading scale assess Palm 7.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 8

Using the 5-POINT grading scale assess Palm 8.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 9

Using the 5-POINT grading scale assess Palm 9.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 10

Using the 5-POINT grading scale assess Palm 10.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with 50% frond loss, but recoverable
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 11

Using the 5-POINT grading scale assess Palm 11.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 12

Using the 5-POINT grading scale assess Palm 12.

Choose:

- ◯ 1. No Damage
- ◯ 2. Damage present with
- ◯ 3. Damage present with 20%–50% frond loss
- ◯ 4. Damage present with >50% frond loss, but recoverable & not dead
- ◯ 5. >95% frond loss, unrecoverable or dead

Palm 13
Using the 5-POINT grading scale assess Palm 13.

Choose:

- 1. No Damage
- 2. Damage present with
- 3. Damage present with 20%–50% frond loss
- 4. Damage present with >50% frond loss, but recoverable & not dead
- 5. >95% frond loss, unrecoverable or dead

Palm 14
Using the 5-POINT grading scale assess Palm 14.

Choose:

- 1. No Damage
- 2. Damage present with
- 3. Damage present with 20%–50% frond loss
- 4. Damage present with >50% frond loss, but recoverable & not dead
- 5. >95% frond loss, unrecoverable or dead

Palm 15

Using the 5-POINT grading scale assess Palm 15.

Choose:

- 1. No Damage
- 2. Damage present with
- 3. Damage present with 20%–50% frond loss
- 4. Damage present with >50% frond loss, but recoverable & not dead
- 5. >95% frond loss, unrecoverable or dead

Palm 16

Using the 5-POINT grading scale assess Palm 16.

Choose:

- 1. No Damage
- 2. Damage present with
- 3. Damage present with 20%–50% frond loss
- 4. Damage present with >50% frond loss, but recoverable & not dead
- 5. >95% frond loss, unrecoverable or dead

Palm 17

Using the 5-POINT grading scale assess Palm 17.

Choose:

- 1. No Damage
- 2. Damage present with
- 3. Damage present with 20%–50% frond loss
- 4. Damage present with >50% frond loss, but recoverable & not dead
- 5. >95% frond loss, unrecoverable or dead

Palm 18

Using the 5-POINT grading scale assess Palm 18.

Choose:

- 1. No Damage
- 2. Damage present with
- 3. Damage present with 20%–50% frond loss
- 4. Damage present with >50% frond loss, but recoverable & not dead
- 5. >95% frond loss, unrecoverable or dead

Palm 19

Using the 5-POINT grading scale assess Palm 19.

Choose:

- 1. No Damage
- 2. Damage present with
- 3. Damage present with 20%–50% frond loss
- 4. Damage present with >50% frond loss, but recoverable & not dead
- 5. >95% frond loss, unrecoverable or dead

Palm 20

Using the 5-POINT grading scale assess Palm 20.

Choose:

- 1. No Damage
- 2. Damage present with
- 3. Damage present with 20%–50% frond loss
- 4. Damage present with >50% frond loss, but recoverable & not dead
- 5. >95% frond loss, unrecoverable or dead

Participant Demographics

Gender

- ◯ Male
- ◯ Female

Age group

- ◯ 18–30 years old
- ◯ 31–40 years old
- ◯ 41–50 years old
- ◯ 51–60 years old
- ◯ Above 60 years old

Which country are you currently residing in?

- ◯ New Zealand
- ◯ Papua New Guinea
- ◯ Solomon Islands
- ◯ Other (Please state country of residence) ____

What is your profession?

- ◯ Student
- ◯ Scientist (Please state which branch of science) ____
- ◯ Other (Please state profession) ____

Have you worked on coconuts or coconut pests before?

- ◯ Yes
- ◯ No

How many years have you worked on coconuts or coconut pests?

- ◯ Less than 2 years
- ◯ 3–5 years
- ◯ 6–10 years
- ◯ 10–20 years
- ◯ More than 20 years

Prior to this survey, did you know what coconut rhinoceros beetle (CRB) is?

- ◯ Yes
- ◯ No, this survey is the first time I have heard about CRB

How do you know about coconut rhinoceros beetle (CRB)?

- ◯ University Lecturer
- ◯ It's part of my line of work
- ◯ Local DPI/ MPI
- ◯ Internet
- ◯ Other (Please state answer) ____

Survey Submission

Thank you for taking the time to participate in this survey. You may at any time **before submitting the survey** withdraw your participation, including withdrawal of information you have provided, however, if you **SUBMIT** the questionnaire, it will be understood that you have consented to participate in the project and to the publication of the end results of the project with the understanding that anonymity will be preserved. Your contribution is appreciated.

- ◯ SUBMIT

Appendix B

Photo Database Results

B.1 Primary dataset

Appendix B.1 5-A: Comparison of undamaged palms between scales

Country	**Total palms**	**Undamaged palms**		
		Binary	3-point	5-point
PNG	97	38 (39.2 %)	37 (38.1 %)	36 (37.1 %)
Solomon Islands	2024	163 (8.1 %)	190 (9.4 %)	144 (7.1 %)
Fiji	228	105 (46.1 %)	93 (40.8 %)	105 (46.1 %)

Compared Scales		**PNG**	**Solomon Islands**	**Fiji**
		P-values	**P-values**	**P-values**
Binary	Vs 3-point	0.999	0.147	0.299
Binary	Vs 5-point	0.883	0.285	1.000
3-point	Vs 5-point	0.999	**0.010**	0.299

Appendix B.1 5-B: Comparison between countries

Scales	**PNG**	**SI**	**Fiji**
Binary	39.2 % (38/97)	8.1 % (163/2024)	46.1 % (105/228)
3-point	38.1 % (37/97)	9.4 % (190/2024)	40.8 % (93/228)
5-point	37.1 % (36/97)	7.1 % (144/2024)	46.1 % (105/228)

Compared countries		**Binary scale**	**3-point scale**	**5-point scale**
		P-values	**P-values**	**P-values**
PNG	Vs SI	**<0.001**	**<0.001**	**<0.001**
PNG	Vs Fiji	0.273	0.711	0.144
Fiji	Vs SI	**<0.001**	**<0.001**	**<0.001**

Appendix B.1 5-C: Comparison of scales in Henderson and GPPOL, the Solomon Islands between January and November 2018

Scales	Henderson January 2018	Henderson November 2018	P-value
Binary	0 % (0/104)	1.9 % (2/104)	0.498
3-point	0 % (0/104)	1.9 % (2/104)	0.498
5-point	0 % (0/104)	0.9 % (1/104)	0.999

Scales	GPPOL January 2018	GPPOL November 2018	P-value
Binary	3.2 % (2/62)	4.2 % (8/190)	0.999
3-point	3.2 % (2/62)	4.2 % (8/190)	0.999
5-point	1.6 % (1/62)	3.2 % (6/190)	0.999

Appendix B.1 5-D: Comparison of dead palms between scales

Country	Total palms	Dead palms	
		3-point	5-point
PNG	97	2 (2.1 %)	2 (2.1 %)
Solomon Islands	2024	209 (10.3 %)	203 (10 %)
Fiji	228	2 (0.8 %)	2 (0.8 %)

Country	Compared scales for dead palms		P-value
PNG	3-point	Vs 5-point	1.000
Solomon Islands	3-point	Vs 5-point	0.795
Fiji	3-point	Vs 5-point	1.000

Appendix B.1 5-E: Comparison of dead palms between countries

Country	Total palms	Dead palms	
		3-point	5-point
PNG	97	2 (2.1 %)	2 (2.1 %)
Solomon Islands	2024	209 (10.3 %)	203 (10 %)
Fiji	228	2 (0.8 %)	2 (0.8 %)

Compared countries		3-point scale	5-point scale
		P-values	P-values
PNG	Vs SI	**<0.005**	**<0.005**
PNG	Vs Fiji	0.586	0.586
Fiji	Vs SI	**<0.001**	**<0.001**

Appendix B.1 5-F: Comparison of scales in Henderson and GPPOL, the Solomon Islands between January and November 2018

Scales	Henderson January 2018	Henderson November 2018	P-value
3-point	15.4 % (16/104)	25.9 % (27/104)	0.286
5-point	14.4 % (15/104)	19.2 % (20/104)	0.459

Scales	GPPOL January 2018	GPPOL November 2018	P-values
3-point	11.3 % (7/62)	17.4 % (33/190)	0.319
5-point	11.3 % (7/62)	16.3 % (31/190)	0.416

B.2 Validation Dataset

Appendix B.2 5-A: Comparison of undamaged palm proportions

Solomon Islands, February 2020	Binary	3-point	5-point
120 palms assessed	5 % (6/120)	5 % (6/120)	4.2 % (5/120)

Solomon Islands (February 2020)		P-values
Binary	Vs 3-point	1.000
Binary	Vs 5-point	0.999
3-point	Vs 5-point	0.999

Appendix B.2 5-B: Comparison of the proportion of undamaged palms in the three scales between Henderson January 2018 and Solomon Islands February 2020.

Scales	Henderson, Solomon Islands, January (2018)	Solomon Islands February (2020)	P-value
Binary	0 % (0/104)	5 % (6/120)	**0.032**
3-point	0 % (0/104)	5 % (6/120)	**0.032**
5-point	0 % (0/104)	4.2 % (5/120)	0.063

Appendix B.2 5-C: Comparison of the proportion of undamaged palms in the three scales between Henderson November and validation data.

Scales	Henderson, Solomon Islands, November (2018)	Solomon Islands February (2020)	P-value
Binary	1.9 % (2/104)	5 % (6/120)	0.290
3-point	1.9% (2/104)	5 % (6/120)	0.290
5-point	0.9 % (1/104)	4.2 % (5/120)	0.220

Appendix B.2 5-D: Comparison of the proportion of undamaged palms in the three scales between GPPOL January and validation data.

Scales	GPPOL, Solomon Islands, January (2018)	Solomon Islands February (2020)	P-value
Binary	3.2 % (2/62)	5 % (6/120)	0.718
3-point	3.2 % (2/62)	5 % (6/120)	0.718
5-point	1.6 % (1/62)	4.2 % (5/120)	0.666

Appendix B.2 5-E: Comparison of the proportion of undamaged palms in the three scales between GPPOL November and validation data.

Scales	GPPOL, Solomon Islands, November (2018)	Solomon Islands February (2020)	P-value
Binary	4.2 % (8/190)	5 % (6/120)	0.783
3-point	4.2 % (8/190)	5 % (6/120)	0.783
5-point	3.2 % (6/190)	4.2 % (5/120)	0.755

Appendix B.2 5-F: Comparison of dead palm proportions

Solomon Islands, February 2020	3-point	5-point	P-value
120 palms assessed	5 % (7/120)	4.2 % (7/120)	1.000

Appendix B.2 5-G: Comparison of the proportion of dead palms in the multi-point scales between Henderson January and the validation data.

Scales	Henderson, Solomon Islands, January (2018)	Solomon Islands February (2020)	P-values
3-point	15.4 % (16/104)	5.8 % (7/120)	**0.026**
5-point	14.4 % (15/104)	5.8 % (7/120)	**0.042**

Appendix B.2 5-H: Comparison of the proportion of dead palms in the multi-point scales between Henderson November and the validation data.

Scales	Henderson, Solomon Islands, November (2018)	Solomon Islands February (2020)	P-values
3-point	25.9% (27/104)	5.8 % (7/120)	**<0.001**
5-point	19.2 % (20/104)	5.8 % (7/120)	**0.003**

Appendix B.2 5-I: Comparison of the proportion of dead palms in the multi-point scales between GPPOL January and the validation data.

Scales	GPPOL, Solomon Islands, January (2018)	Solomon Islands February (2020)	P-values
3-point	11.3 % (7/62)	5.8 % (7/120)	0.241
5-point	11.3 % (7/62)	5.8 % (7/120)	0.241

Appendix B.2 5-J: Comparison of the proportion of dead palms in the multi-point scales between GPPOL November and the validation data.

Scales	**GPPOL, Solomon Islands, November (2018)**	**Solomon Islands February (2020)**	**P-values**
3-point	17.4 % (33/190)	5.8 % (7/120)	**0.003**
5-point	16.3 % (31/190)	5.8 % (7/120)	**0.007**

Appendix C

Online Survey Results

Online Survey

Appendix C 5-A: Comparison of the scales as a whole

Scales	Correct answers	Incorrect answers
Binary	53	188
3-point	24	217
5-point	0	241

Compared Scales		P-value
Binary	Vs 3-point	**< 0.001**
Binary	Vs 5-point	**< 0.001**
3-point	Vs 5-point	**< 0.001**

Appendix C 5-B: Comparison of individual responses within a scale

Scales	Correct answers	Incorrect answers	Total
Binary	4037	783	4820
3-point	4025	795	4820
5-point	3166	1654	4820

Compared Scales		P-value
Binary	Vs 3-point	0.762
Binary	Vs 5-point	**<0.001**
3-point	Vs 5-point	**<0.001**

Appendix C 5-C: Influence of Experience

Scales	Experienced	Inexperienced	P-value
Binary	8.1 % (107/1320)	19.3 % (676/3500)	**<0.001**
3-point	12.7 % (168/1320)	17.9 % (627/3500)	**<0.001**
5-point	29 % (383/1320)	36.3 % (1271/3500)	**<0.001**

Appendix C 5-D: Influence of Profession

Scales	Others	Scientist	Student
Binary	16.7 % (287/1720)	15 % (354/2360)	19.2 % (142/740)
3-point	17.7 % (305/1720)	15.8 % (373/2360)	15.8 % (117/740)
5-point	34.5 % (593/1720)	33.4 % (789/2360)	36.8 % (272/740)

Professions		Binary scale	3-point scale	5-point scale
		P-value	**P-value**	**P-value**
Scientist	Vs others	0.151	0.106	0.503
Student	Vs others	0.147	0.268	0.290
Student	Vs scientist	**0.008**	0.999	0.100

Appendix C 5-E: Influence of Place of Residence

Scales	Place of Residence			
	Asia	**ANZ**	**Pacific**	**Others**
Binary	7.8 % (14/180)	19.1 % (605/3160)	7.2 % (68/940)	17.8 % (96/540)
3-point	10 % (18/180)	17.2 % (545/3160)	14.1 % (133/940)	18.3 % (99/540)
5-point	30 % (54/180)	34.8 % (1100/3160)	31.5 % (296/940)	37.8 % (204/540)

Place of Residence		Binary	3-point	5-point
		P-value	**P-value**	**P-value**
Asia	Vs ANZ	**<0.001**	**0.010**	0.198
Asia	Vs Pacific	0.756	0.153	0.726
Asia	Vs others	**0.001**	**0.010**	0.060
ANZ	Vs Pacific	**<0.001**	**0.024**	0.060
ANZ	Vs Others	0.476	0.539	0.188
Pacific	Vs others	**<0.001**	**0.037**	**0.014**